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Developing Industrial Ecosystems: Approaches, Cases, and Tools

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Developing Industrial Ecosystems: Approaches, Cases, and Tools

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Contents

PART IV: THE URBAN CONTEXT– STUDYING NEW HAVEN

PART V: EXERCISES FOR EXECUTIVE EDUCATION AND CLASSROOM USE

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Welcome to Readers

The reports contained in this volume highlight five years of research conducted as part of the Industrial Ecology course at the Yale School of Forestry & Environmental Studies. Industrial ecology, which has been termed the science of sustainability, encompasses studies of the flow of materials and energy at different scales. These papers propose innovative ideas for improving the environmental performance of industrial activities, ranging from energy production to food processing to electronics disposal.

The industrial ecosystem concept explored in this publication is a major focus of research by Dr. Marian Chertow, the Director of the Industrial Environmental Management Program at Yale F&ES and the editor of this volume. As with their counterparts in natural systems, symbiotic relationships in industrial ecosystems are characterized by mutual interdependence. Industries are linked through exchanges whereby the wastestream of one company becomes the input of another.

The breadth of industrial ecosystem case study research offered here is unique. Students have examined not only established industrial eco-parks around the world, but have also developed hypothetical relationships among existing companies with the goal of optimizing resources, energy, and capital.

This research exemplifies the kind of forward thinking that the Yale Center for Industrial Ecology (CIE) was established to support. Since its foundation in 1998, CIE has provided an organizational focus for research that helps to develop new knowledge at the forefront of the field of industrial ecology. Research is carried out in collaboration with other segments of the Yale community, with other academic institutions, and with international partners on many continents.

We hope that the ideas within these pages help to advance new perspectives on industrial development. Whether a student of the environment or business, a developer, an entrepreneur, or an urban planner, readers will be challenged by the ideas within this Bulletin to rethink conventional assumptions about the relationship between industrial development, natural systems, and economic growth.

Sincerely,

Thomas E. Graedel
Clifton R. Musser Professor of Industrial Ecology
Director, Yale Center for Industrial Ecology

Acknowledgements

It seems fitting that this publication on industrial symbiosis is the result of mutually beneficial relationships, sharing of information, and efforts to identify resources in somewhat unlikely places. We attempt to thank our human partners here.

First, we wish to recognize those people whose firms and organizations were directly related to these papers and who actively cooperated with us. They provided time, but more importantly, they shared insight and invaluable contextual information with the authors. We thank John Anderson, James Austin, Walt Carey, Jim Dougherty, Bryan Garcia, Joel Gordes, Alvaro Lima, Rogelio Magat, C.J. May, Dave Rejeski, Don Roe, Robert Rosenberg, Kevin Pearce, Bill Stillinger, and one of our authors, Bob Tierney of Pratt & Whitney. Peter Lowitt is an eco-park pioneer, now at Devens Enterprise Center, and he gave us many opportunities and much advice. Justin Bielagus and his partner Robert Cruess welcomed us in Londonderry, New Hampshire, twice, and then went on to teach us many valuable lessons about real eco-industrial park development. Pat Mahoney raised our level of analysis and allowed us to try to connect many dots between industry and agriculture in Puerto Rico.

Last year, Karyn Gilvarg and Mike Piscatelli at the New Haven City Plan Department became wonderful partners in our efforts to reconceptualize the potential of the New Haven Harbor, pictured on the volume cover. We suspect they have not seen the last of us.

Our deepest thanks go to Jane Coppock, Assistant Dean of the Yale School of Forestry & Environmental Studies and editor of the Bulletin Series, who guided this volume to its final form with her support and expertise. We are also grateful to the students who reviewed the papers and provided essential assistance: P.J. Deschenes, Marjorie Huang, Cherie LeBlanc, Marissa Kantor, Liz Roberts, Kristin Sipes, Josh Slobin, with special thanks to April Reese. Robert Klee, who co-authored one of the included papers as a Master's student, is now pursuing his Ph.D. at the School, and has been a loyal colleague, teaching and research assistant, and friend.

Our colleagues, Tom Graedel, Director of the Center for Industrial Ecology, and Reid Lifset, Editor of the Journal of Industrial Ecology, who, together with Marian Chertow, taught the class from which this publication grew, have been instrumental in the project. Our Dean, Gus Speth, is a great supporter and we are thankful for his interest in all of the projects of the Center for Industrial Ecology.

We would like to recognize the research done by those who have helped to advance what we have called industrial symbiosis operating in industrial ecosystems, but which others might include under the broader rubric of eco-industrial development. John Ehrenfeld and Jørgen Christensen taught us what we know about the great archetype in Kalundborg, Denmark. David Cobb of Bechtel developed the idea of the virtual eco-industrial park and worked with us on computer modeling. Ernie Lowe has been a wonderful

inventor, inspirer and resource not only for the authors of these papers, but also for the field that has grown up around industrial symbiosis. The biggest advocate, following the promotion of these ideas at the President's Council for Sustainable Development in the mid-90's, has been Ed Cohen-Rosenthal and the staff at the Cornell Work and Environment Initiative. Ed kept the parties meeting and the website growing. His death during January of 2002 is a loss heard round the eco-industrial development world. We'll miss him.

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Marian Chertow and Michelle Portlock
February 2002

Introduction

Marian Chertow
Director, Industrial Environmental Management Program
Yale School of Forestry & Environmental Studies

Each paper in this compendium presents a vision of how firms can reach beyond their usual boundaries to achieve greater environmental and financial results. Each vision includes a network of organizations sharing basic inputs and outputs such as raw materials, process wastes, energy, water. The core idea is that one organization's waste can become another organization's feedstock. Thus, the papers illustrate how networks of firms in geographic proximity can benefit from a cooperative approach to competitive advantage.

We have come to call these networks "industrial ecosystems" because, like nature's ecosystems, they involve a web of connections based on the cycling and adaptive use of energy and materials.[1] The fourteen industrial ecosystems described in this volume are presented by students at the Yale School of Forestry & Environmental Studies. The students were assigned a real world setting to use as the basis for the design of an industrial ecosystem using the principles of industrial ecology. A new field, industrial ecology requires "that an industrial system be viewed not in isolation from its surrounding systems, but in concert with them" (Graedel and Allenby 1995). Thus, by focusing on industrial operations in the context of the surrounding air, water, and land use systems in which they are part, more integrative solutions are possible (see Figure 1).

One of the inspirations for the field of industrial ecology comes from the small town of Kalundborg, Denmark, where an extraordinary inter-firm

[1] Frosch and Gallopoulos, in a 1989 article that is considered, perhaps, the founding of industrial ecology, describe an industrial ecosystem in which "the consumption of energy and materials is optimized and the effluents of one process...serve as the raw material for another process" (Frosch and Gallopoulos 1989). See also Frosch 1994. The term "industrial ecosystem" was further popularized in a book published by the National Academy of Engineering (Allenby and Richards 1994). The geographically-based systems described in this compendium are one type of industrial ecosystem. Other types in the NAE study include the lifecycle of a single product or material, an industry, or a group of interrelated subsystems at different temporal or spatial scales.

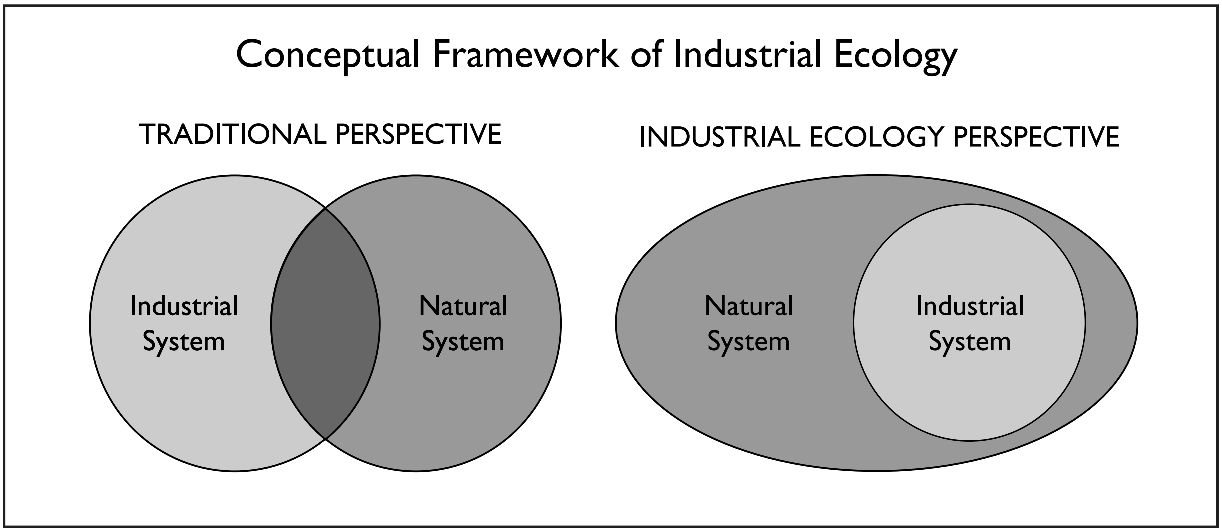

Figure 1 Conceptual Framework of Industrial Ecology

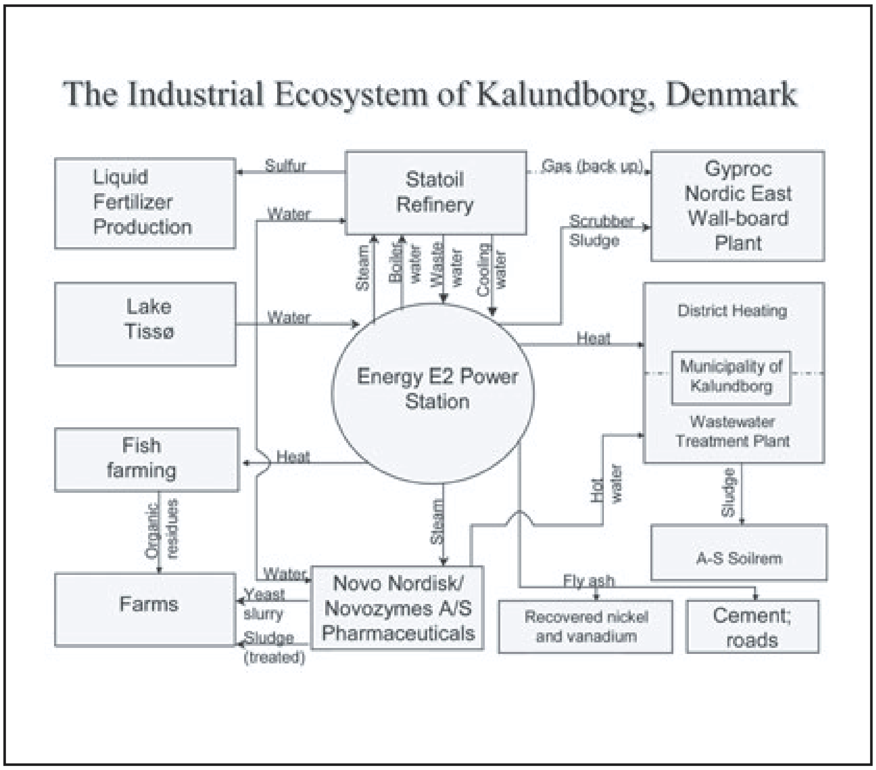

Figure 2 The Industrial Ecosystem of Kalundborg, Denmark
Source: M. Chertow, 2001. 2002 Update, Noel Jacobsen, University of Copenhagen

network has developed gradually over the past several decades. As shown in Figure 2, there are now some twenty resource exchanges in this industrial ecosystem involving an oil refinery, power station, gypsum board facility, pharmaceutical plant, and the Municipality of Kalundborg, among others. The participants literally share ground water, surface and waste water, steam, and electricity, and also exchange a variety of residues that become feedstocks in other processes. This cooperation has significantly increased environmental and economic efficiency.[2]

Certainly, a new name was needed to characterize what had been occurring in Kalundborg for many years in this model industrial ecosystem. The manager of the Asnaes power station in Kalundborg drew upon the biological term, symbiosis, which describes the condition where at least two participants exchange materials, energy, or information in a mutually beneficial manner.[3] He chose the name "industrial symbiosis" to describe these place-based exchanges among different entities.[4] Oddly, Kalundborg's symbiosis was not planned, but evolved over time and has changed often since its beginnings 30 years ago (Ehrenfeld and Chertow 2002). In addition to physical resource exchanges, industrial ecosystems, as in Kalundborg, also benefit from sharing of information, equipment, and personnel. As described here, the symbioses need not occur within the strict boundaries of a "park," despite the popular

[2] The waste exchanges alone amount to some 2.9 million tons of material per year (Lowe *et al.* 1995). Water consumption has been reduced by a collective 25% and 5000 homes received district heat (The Symbiosis Institute).

[3] Technically, there are three forms of biological symbiosis. The form generally referred to here is where two or more organisms find benefit, which is called "mutualism." The other forms are "commensalism," in which one party benefits and the other is unaffected, and "parasitism," in which one party benefits and the other is harmed (Miller 1994).

[4] Engberg 1993 credits Valdemar Christensen, former manager of the power station, with coining the phrase "industrial symbiosis" and defining it as "a cooperation between different industries by which the presence of each... increases the viability of the other(s), and by which the demands [of] society for resource savings and environmental protection are considered." The notion of symbiosis has been celebrated in Kalundborg by artists and poets (Christensen 1993; Christensen 1998) We use the terms "industrial ecosystem" and "industrial symbiosis" roughly interchangeably in this volume, since the kind of symbiosis described in these papers is the principal type of industrial ecosystem being studied.

usage of the term "eco-industrial park" to describe a group of organizations engaging in exchanges.

The result of each study included here is a plan for linking surrounding enterprises together in some form of symbiotic activity. It is important to say that while the settings are real, the outcomes are invented. The papers fulfill the clinical requirement of Yale's graduate level course called "Industrial Ecology." They are academic exercises in the best sense: not only do they provide a learning experience for the students who must think through the possible systems links, but these papers are themselves illustrations of new principles, tools and strategies that are shaping further development of industrial symbiosis. Thus, the purpose of publishing these student papers is twofold: we wish to inspire as well as to educate, to suggest concretely how industrial ecology visions can be implemented, and to offer these tools and strategies to everyone in the global community who may become interested in this challenge.

Ultimately, industrial symbiosis and industrial ecology broadly are aspects of sustainable development, the elusive quest to harmonize environment and economy. Some say that sustainable development is merely a story line that generated world attention precisely because of its ambiguity (Hajer 1996). The optimistic side of this formulation is that locally, each of us can tell our own stories of sustainability by participating in industrial symbiosis. Self-organizing networks can happen, where economically feasible, with a bit of vision and surrender. They can be new industrial developments planned from scratch or, more importantly, they can connect existing infrastructure in urban and suburban contexts. While perhaps at times idealistic, most of all this collection demonstrates creative reassembling of pieces to enable superior economic and environmental performance.

PROJECTS COMPLETED

Since the spring of 1997, 31 studies have been conducted at Yale that involve many different types of physical inter-firm connections at varying scopes and scales. The choice of these projects was experimental, designed to gain experience in a variety of different field settings in a way that would allow us to explore the process, practice, and potential of industrial symbiosis more closely. Reviewing the applied research literature, we were reminded of the importance of "conducting formative studies, ones that are intended to help improve existing practice rather than simply to determine the outcomes of the program or practice being studied" (Maxwell 1998). We divided each class into teams of three to five students, assigning each team to an industrial symbiosis project.

According to materials prepared for the class,

> "Project selection was based, first of all, on whether the project lent itself to the application of industrial ecology concepts. It was also important to achieve a diversity of projects 1) by industry type, 2) by stage of development, and 3) along a spatial continuum from a single product or facility to co-located facilities to multi-company exchanges located on dispersed sites. Additional consideration was given to distance from New Haven, opportunities for creative applications, and willingness and congeniality of the host contact."

One of the first results to come from this study was the emergence of a taxonomy to describe material exchange types spatially and organizationally (Chertow 1999, 2000). These are discussed here as Types 1-5 and are listed below:

> Type 1: **Through waste exchanges.** These are typically one-way exchanges that are generally focused at the end-of-life stage of a product or process such as used clothes for charity, scrap-metal or paper collection, or industrial by-products offered for sale, for example, at internet websites.
>
> Type 2: **Within a facility, firm, or organization.** Typically, these occur in a larger organizational unit that often behaves as if it were a collection of separate entities.
>
> Type 3: **Among firms co-located in a defined eco-industrial park.** This is the idealized form where physical and informational sharing primarily occur within set boundaries.
>
> Type 4: **Among local firms that are not co-located.** Here, the primary partners need not be contiguous, but are within a small area geographically as in Kalundborg, Denmark.
>
> Type 5: **Among firms organized "virtually" across a broader region.** While still place-based, the greater spatial spread decreases the types of exchanges (such as energy, which is harder to share beyond a couple of miles) but increases the number of firms that can participate, especially in by-product exchanges.

By definition, Types 3-5 offer approaches that can readily be identified as industrial symbiosis. From 1997 to 2000, the Industrial Ecology class explored 23 projects of all types as noted in Table 1.

Table 1 Industrial Ecosystem Projects Conducted at Yale from 1997-2000

Type 1	Web-based exchanges (2001)
Type 2	Yale University electronics recycling (1998) **
	United Technologies process (1998)
	United Technologies facility (1999)
	Integrated bio-system - mushroom study (2000) **
Type 3	New Haven Science Park (1997)
	Clark Special Economic Zone - Philippines (1998) **
	Londonderry, New Hampshire I (1997)
	Londonderry, New Hampshire II (1998)
	Danbury landfill gas-to-energy (1998)
	Groton landfill gas-to-energy (1998)**
	Recycled newsprint facility (1998) **
	Green Triangle of Boston (1999) **
	Devens Enterprise Center (2000)
	Bio-mass energy project (2000)
Type 4	Organics residue recycling - New Milford (1997) **
	Montville eco-industrial system (1997) **
	Sustainable agriculture support cluster - Puerto Rico (1999) **
	Bridgeport waste-to-energy (1999)
	Industrial symbiosis in Japan (2000)
	Wallingford eco-industrial park (1999) **
Type 5	Matchmaker! software project (1997) **
	Industrial symbiosis for food residues (1998) **

The projects marked ** are included in this volume. In addition to these 23 projects, eight more were conducted in 2001, all around the theme of understanding material and energy flows near the New Haven Harbor. Two of the New Haven Harbor papers, one on food cycling and one exploring a specific neighborhood around the harbor, have also been included.

While each of the papers is interesting in its own right and, together, they examine a wide range of economic settings, the papers included in this volume were chosen because they clearly illustrate a particular feature of industrial symbiosis research. Some of those excluded are actual project sites that might have included proprietary data or where the analysis done by the students may have been superceded by events. Londonderry, New Hampshire, for example, which we studied twice, now has perhaps the best example of a U.S. eco-industrial park under development. In other cases, the paper selected serves as a model for a lesson several papers illustrated.

DESCRIPTION OF THE PAPERS

The focus of this five-part volume is educational. The five papers of Part I were chosen to highlight various tools of industrial ecology that can be used to conduct industrial symbiosis analyses. Four papers in Part II present important strategic issues including barriers to smooth functioning of industrial ecosystems as well as critical starting points around which to organize an industrial symbiosis. A special class of industrial ecosystems, known as integrated bio-systems, are based on material and energy exchanges in agricultural settings and two papers are included on this subject in Part III. Because of the implications of industrial symbiosis for economic development, Part IV includes four papers that consider New Haven, Yale's host city, and different aspects of how industrial symbiosis can be applied in an urban context. Table 2 highlights one key lesson from each paper in Parts I through IV.

Part V of this volume includes a primer on eco-industrial development and two versions of an exercise we have used for executive training in New Haven and in China. In an effort to engage participants and to give them a concrete feel for the possibilities of symbiosis, the exercises lay out elements of a local industrial area and ask teams how they might assemble the pieces into an industrial ecosystem. We include these group exercises on industrial symbiosis in the hope that others might pick them up and adapt them for further use and discovery.

Table 2 Review of Papers in Parts I-IV and Illustrative Lessons Learned

SELECTED PAPER	LESSON ILLUSTRATED
PART I Tools from Industrial Ecology	
Yale Electronics	Budgeting to map material and energy flows
New Milford Farm	Grand nutrient cycles – study of nitrogen cycling
Groton Landfill Gas	Using matrix assessment and economic analysis
Matchmaker!	Creating a data base for input-output matching
Clark Economic Zone	Stream-based analysis of an existing industrial park
PART II Strategies and Opportunities	
CT Newsprint	Planning an industrial ecosystem from scratch
Montville Eco-Industrial System	Leveraging one exchange – steam sharing – into many
Wallingford Industrial Area	The problem of scale within an existing group of businesses
Green Triangle	Augmenting traditional cluster analysis to include material and energy flows
PART III Integrated Bio-Systems	
Mushroom Bio-System	Increasing cycling in mushroom production
Sustainable Agriculture Cluster	How an industrial system can integrate agricultural elements
PART IV The Urban Context - Studying New Haven	
Food Residues	Selecting an appropriate industry for analysis
Food Cycling	Integrating historical legacy with future economic development
English Station West	Analyzing an existing geographic cluster in an old urban neighborhood

PART I: TOOLS FROM INDUSTRIAL ECOLOGY

In these five studies of industrial ecosystems, several tools, often introduced in class, proved useful to many of the student teams as discussed below.

Yale University Electronics Recycling

The first significant tool is the materials budget used to map the flow of inputs and outputs through the system under study, which is a basic building block of any industrial symbiosis analysis. In a telling example, students measured the flow of one product, personal computers, through the Yale University industrial ecosystem. They estimated there were 4500 computers entering the university each year, other than those personally owned, yet only 227 were known to be exiting the system through recycling and donations to other organizations. The materials budget requires that all system flows be identified, so a user survey was conducted. Because computers last for several years, most were determined still to be in active use. Based on the survey, however, as many as 1000 units were estimated to have become obsolete. In order to account for these computers, which had not shown up for collection, the implication of the materials budget was that these units had most likely become "closetfill"– neither recycled nor disposed, but tucked away in cubbies and closets everywhere.

New Milford Farms and Organic Residue Recycling

Students assigned to New Milford Farms, a food composting operation in western Connecticut owned by Nestlé USA, investigated enhancing the composting program there. They examined the feasibility of using organic waste streams from several nearby facilities to augment the current system, which relied primarily on coffee grounds and spent tea leaves from other Nestlé operations. Reading like a primer on composting of organics, the paper examines the global nitrogen cycle and consider the potential to replace commercial fertilizers with compost-based organic fertilizers.

The Power of Trash: Harnessing Electricity, Carbon Dioxide, and Heat from a Landfill's Methane Gas

A key question that arises in an industrial symbiosis analysis is whether a proposed system is in some way "greener" or "better" than the existing one. A comparative tool selected by many teams was the "abridged life cycle assessment matrix" known more familiarly as the "Graedel matrix." This semi-quantitative tool assigns a rating of 0-100 to a product, process, service, or facility based on five environmental criteria examined over five life cycle stages so various options can be prepared on the same grid (Graedel 1998).

In this analysis of a landfill gas-to-energy project at the municipal landfill in Groton, Connecticut, a stationary fuel cell was already in place to convert methane to energy. Like other business operators, the project sponsor, Northeast Utilities, wanted to know what the best option was for reuse of the captured by-products on a lifecycle basis. The Groton landfill team used a Graedel matrix assessment, revised to include economic considerations, to compare four scenarios for reuse of CO_2 as a by-product of the landfill gas-to-energy process. According to this analysis, the greatest economic, environmental, and social value lay in generating energy and selling the CO_2 rather than using it for greenhouse operations.

The Matchmaker! System: Creating Virtual Eco-Industrial Parks

Another key question in developing an industrial symbiosis is how to determine input-output matches among companies and organizations. Conceivably, a computer program could help to determine what material streams would support which industries and, conversely, how by-products of existing industries could be used as raw materials to attract new industries. One student team, in 1997, prepared a personal computer-based model dubbed "Matchmaker!" based in part on initial work done by David Cobb and others at Bechtel Research and Development. The tool was designed to find outlets for reusing materials based on generic descriptions of candidate companies. These were dubbed "virtual" eco-industrial parks because, by concentrating on material exchanges rather than water or energy, companies within a broader geographical area, such as fifty miles, could participate in the industrial symbiosis.

By 1998, the U.S. Environmental Protection Agency (U.S. EPA) had commissioned a more elaborate computer model for input-output matches. Students in the 1999 session were able to use a CD ROM containing the EPA models known as FaST (Facility Synergy Tool), DIET (Designing Industrial Ecosystems Tool), and REaLiTy (Regulatory, Economic, and Logistics Tool (U.S. EPA 1999). These models are planning tools that allow a community to investigate whether the addition of specific types of industries might enhance industrial symbiosis. Actual experience with material matching among existing companies in a six county area was gained over several years through a project conducted by North Carolina's Triangle J Council of Governments (Kincaid and Overcash 2001).

Clark Special Economic Zone:
Finding Linkages in an Existing Industrial Estate.

The challenge to the Clark team was to find linkages among 200 companies in a recently developed industrial estate in the Philippines. Adaptive reuse of the former Clark Air Base, decommissioned by the U.S. Air Force, had led to diverse economic activity in industries ranging from electronics to tobacco to plastics to textiles. The study, conducted from afar by the students, used a technique I have since called "stream-based analysis." The team grouped the occupants at Clark by common flows, such as who was using, or could use, solvents, oil, rubber, or compost. They approached industrial symbiosis as a means of networking the primary users of each stream. In this way, they were able to come up with material flows that would maximize the use and reuse of each stream. While many project developers think secondarily about flows and primarily about filling real estate in what I have called the "business-based model" this chapter shows how stream-based analysis can reveal many opportunities (Chertow 1999).

PART II: STRATEGIES AND OPPORTUNITIES

Each of the papers in this section has a distinct strategic premise. The first paper plans an industrial symbiosis from scratch based in a particular industry, the second builds from an existing exchange between two firms to many exchanges, the third looks specifically at the problems and opportunities of linking an existing cluster of businesses with related inputs and outputs, and the fourth links existing not-for-profit organizations.

Connecticut Newsprint:
A Conceptual Model for Eco-Industrial Material Flows

This project, based around the newspaper business, designs an idealized form of an eco-industrial park in which all facilities are located on a common piece of real estate. The core of the project is a de-inking operation that accepts recycled newsprint as a feedstock, removes the ink chemically, and converts the remainder to a recycled pulp product used to make new newspaper. The student team began with the de-inking business, and used knowledge of the flows into and out of the plant of streams, such as newsprint, sludge, water, and other materials, to propose an eco-industrial park that would include an on-site publisher, composting operation, and building materials manufacturer. This paper, as well as the one which follows, presents a good balance of a stream-based with a business-based approach.

AES-Thames and Stone Container Corporation:
Montville Eco-Industrial System

The "anchor" of this project is an existing co-generation operation, involving a coal-fired power plant and a boxboard manufacturer in Montville, Connecticut. Although the steam needs of Stone Container Corporation were being met, there was additional steam that could be used for other operations. Upon investigation, the student team found other applicable resources in the community such as a municipal sewage treatment plant and underutilized agricultural land. Combining all of the flows conceptually, the team proposed a business based on the streams. Specifically, the team proposed siting a brewery that would grow hops on the nearby agricultural land with biosolids from the sewage plant, use steam from the coal plant to power the brewing, and package the final product in cardboard from the boxboard plant. The major business missing was a supplier of plastic strapping, so the students searched and found a supplier in a nearby state.

This approach has as its kernel the existing co-generation exchange. Known in the literature as "green twinning," or "by-product synergy," it is much easier to identify and implement one exchange, such as co-generation in the Montville project or landfill gas-to-energy in Groton, and then use it to springboard other exchanges. Indeed, there are hundreds, if not thousands, of instances of green twinning in the United States alone, enough to convince many business leaders that this is not novel or risky, but a proven means of "resource productivity." Each can be viewed as the first stages of broader industrial symbiosis.

Wallingford, Connecticut, Eco-Industrial Park: A Question of Scale

The Wallingford team carefully investigated existing facilities including three steel companies, a chemical company, a concrete company, and a waste-to-energy plant in an industrial area of Wallingford, Connecticut. As in other papers, the team sought to determine what exchanges 1) might already be possible, 2) could develop cooperatively, and then 3) what new businesses could be brought in to benefit from existing raw materials, including the team's notion of adding an "industrial campground" for provision of common services. Mixing new and existing facilities is another way to maximize opportunities from industrial symbiosis.

The Wallingford project team raised the issue of scale in considering the viability of medium-sized eco-industrial parks. The team found, for example, significant amounts of metal scrap, some 18 million pounds per year, but this was still an order of magnitude below the tonnage needed to build and run a mini-mill. Neither did the types of metal scrap match across the three participating plants. The team recognized that,

> ...existing businesses are limited in the quantity of materials that they can provide to residue processors or purchase from new suppliers. It is questionable whether these transactions will be sufficient as to merit the siting of a new facility...If these barriers cannot be overcome, the viability of eco-industrial park development may be dependent upon shrinking the minimum efficient scale of target industries" (Johnson *et al.* 1999).

The Green Triangle of Boston, Massachusetts: An Eco-Industrial Cluster

Business strategist Michael Porter is well known for his research on "clusters." Porter defines clusters as "geographic concentrations of interconnected companies and institutions in a particular field" (Porter 1998). Most familiar, perhaps, in the U.S. are Silicon Valley, the California wine cluster, the home furniture cluster of central North Carolina, and Wall Street. Even in a global economy, Porter finds cluster theory to be more relevant than ever, in that "the enduring competitive advantages in a global economy lie increasingly in local things – knowledge, relationships, motivation – that distant rivals cannot match" (Porter 1998). Industrial symbiosis is a local phenomenon and, like clusters, offers a new way to think about economic development and the roles of businesses and institutions.

Interestingly, one of the Yale teams worked closely with a national group Porter established to examine "the competitive advantage of the inner city" (Porter 1995). Boston Advisors had been working with a large inner-city area in Boston known as the Green Triangle including a zoo, botanical garden, and other significant open space. The Yale team worked with Boston Advisors to enhance its study of how to attract more visitors by bringing focus to environmental aspects. The team found that a key locational advantage shared by the organizations that had yet to be exploited was the opportunity for industrial symbiosis.[5] Since organic residues dominated the input/output cycles of most of the organizations, the team envisioned creating a central composting facility as a means of organizing and coordinating the flow of materials among the sites, along with many spin-off opportunities.

Without an awareness of industrial symbiosis and industrial ecology more broadly, these opportunities had been overlooked. Thus, the team concluded that its experience "evaluating the potential for an eco-industrial park in an area targeted for revitalization has illustrated substantial value in combining efforts to increase efficiency and exchange materials among firms with redevelopment initiatives" (Kellogg *et al.* 1999).

PART III: INTEGRATED BIO-SYSTEMS

The two papers in this section focus on a variation of industrial symbiosis involving agriculture which has taken the name "integrated bio-systems." Many of the systems are being started in developing countries and are actively tracked at United Nations University in Tokyo (UN University 1996).

Integrated Bio-Systems: Mushrooming Possibilities

Although traditional agricultural systems reused every possible output, such frugality seems to have been lost in modern industrialized agriculture. This paper examines the opportunity to offer a "zero-waste" production process for mushroom farming by identifying options for reuse of spent mushroom substrate. Two models considered for a mushroom integrated bio-system are to use the spent substrate for energy in the form of biogas or to use it as an input to another agricultural process, mychorrhizae cultivation. The paper views the addition of a biological sub-system to the already established mushroom farm as a new business opportunity incorporating environmental benefits.

Waste Equals Food: Developing a Sustainable Agriculture Support Cluster for a Proposed Resource Recovery Park in Puerto Rico

In this case, the team examined a proposal to put an eco-industrial park on abandoned agricultural land in Arecibo, Puerto Rico. The industrial proposal was planned at the site of an old paper mill and sugar cane plant. It sought to use a waste-to-energy facility as an anchor tenant for several new companies as well as a redeveloped paper manufacturing operation. The study question was whether some part of the agricultural legacy might be revived and whether agricultural activities could be connected to the proposed industrial development. The paper outlines numerous sustainable agriculture options and uses a version of the matrix analysis tool described above to determine whether

[5] While Porter has often involved himself with environmental competitiveness issues in his research and writing, including his groundbreaking 1995 article with Claas van der Linde on resource productivity, "Green and Competitive: Ending the Stalemate," he did not explicitly consider the kinds of gains that can be made from an industrial symbiosis model, although the authors note, generally, the value of improved utilization of by-products, reduced energy consumption, and conversion of waste into valuable forms as benefits of resource productivity (Porter and van der Linde 1995).

phasing in more options increases the matrix "score," suggesting greater environmental benefit was being achieved.

PART IV: THE URBAN CONTEXT – STUDYING NEW HAVEN

As Yale's host city, New Haven has been studied by Yale affiliates on a vast array of topics over the last centuries. Since industrial ecosystems are place-based, once again New Haven provided a convenient venue.

Efficacy of Industrial Symbiosis for Food Residues in the Greater New Haven Area

Industrial symbiosis is generally characterized as including "species diversity" – that is, involving several different industries rather than only one. This paper, however, explores opportunities for exchange, including longer distance exchanges as in the "virtual eco-industrial park" model, within a single industry. The team decided to pick an industry of importance to the Greater New Haven economy, and study it for possible linkages. The paper reveals how they carefully chose the food industry and then studied it along the value chain from wholesale operations to reuse at food banks. In analyzing possible linkages of products and wastes, one idea was to establish a pet food company using many of the food residue streams.

Food Cycling within New Haven: Creating Opportunities for Economic, Civic, and Environmental Progress Through Industrial Symbiosis

Picking up where the previous paper left off with its selection and analysis of the food industry, this paper explored the legacy of food in New Haven surrounding, in particular, pizza, beer, and the oyster industry, and proposed specific projects in New Haven for food cycling. The paper was tied to a broader study of material flows in and around the New Haven Harbor area completed in conjunction with the New Haven City Plan Department.

Industrial Symbiosis in New Haven Harbor: English Station West

This paper is part of the New Haven Harbor study mentioned above. It is an excellent model of how to conduct industrial symbiosis analysis in an existing urban industrial area. Having reviewed the current business mix, the team focuses on the potential of these companies to tie in with plans to recommission an old power plant. If, for example, the power plant implements a program to co-generate and transport steam, one of the environmental benefits that will be possible from the cooperative arrangements is the opportunity to shut down a diesel boiler at an existing paper plant.

FUTURE DIRECTION

The Yale Center for Industrial Ecology continues to track eco-industrial developments. On the one hand, we recognize that the problems of involving multiple parties in a project are many. Increased planning, transaction costs, and coordination are added to the already formidable list of items requisite in any significant development. In the field, the students sometimes found that even explaining the concept of industrial ecosystems – the educational component – was arduous.

On the other hand, interdependence can bring benefits as well as costs. It should be clearly recognized that all businesses are already interdependent in that each is situated in a de facto network of suppliers, customers, distributors, and other partners. Location within an industrial ecosystem can shorten the distances between suppliers and customers. Further research through the Center for Industrial Ecology will measure the positive aspects of networks involved in physical exchanges, both to the companies involved and to the regions in which they are located.

Another significant avenue of research for the Center for Industrial Ecology is to assess, more formally, the potential of industrial symbiosis as a means of economic development. Successful industrial symbiosis creates raw material streams rather than wastes, and these raw material streams can feed new businesses. This offers true value-added for an in-coming company, a feature that could greatly aid business attraction.

Although industrial symbiosis is still rare in practice, the papers in this volume illustrate the breadth of the concept and its applicability in a wide range of settings. Indeed, it seems odd that such a simple and appealing concept has achieved relatively little notice. Industrial symbiosis is an invitingly concrete, rather than vaguely abstract, approach to sustainable development.

We hope that these papers do inspire as well as educate. Congratulations to the authors, our students and alumni, as they pave a new way for sustainability at the local level.

REFERENCES

Allenby, Braden R., and Deanna J. Richards. 1994. *The Greening of Industrial Ecosystems.* Washington DC: National Academy Press.

Chertow, Marian R. 2000. Industrial Symbiosis: Literature and Taxonomy. *Annual Review of Energy and Environment* 25.

Chertow, Marian R. 1999. Industrial Symbiosis: A Multi-Firm Approach to Sustainability. Greening of Industry Network Conference, November 15.

Christensen, Inge. 1993. *Symbiose.* Kalundborg, Denmark.

Christensen, Valdemar. 1998. Personal Communication. Kalundborg, Denmark.

Ehrenfeld, John and Marian R. Chertow, 2002. Industrial Symbiosis: the Legacy of Kalundborg. In *Handbook of Industrial Ecology*, edited by R. Ayres and L. Ayres. Cheltenham U.K.: Edward Elgar.

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

Frosch, R. 1994. Industrial Ecology: Minimizing the Impact of Industrial Waste. *Physics Today*: 63-68.

Frosch, R., and N. Gallopoulos. 1989. Strategies for Manufacturing. *Scientific American* 261 (3):144-152.

Graedel, Thomas. 1998. *Streamlined Life-Cycle Assessment.* Englewood Cliffs, N.J.: Prentice Hall.

Graedel, Thomas, and Braden Allenby. 1995. *Industrial Ecology.* Englewood Cliffs, N.J.: Prentice Hall:9.

Hajer, Maarten A. 1996. Ecological Modernisation as Cultural Politics. In *Risk, Environment and Modernity: Towards a New Ecology (Theory, Culture and Society)*, edited by S. Lash, B. Szerszynski, and B. Wynne: Sage Publications.

Johnson, Sarah, Stewart Stewart, Bob Tierney, and Alice Walker. 1999. Wallingford Eco-Industrial Park. New Haven, Connecticut: Yale School of Forestry & Environmental Studies.

Kellogg, Terry, John-Phillip Neill, Douglas Pfeister, and Susan Wueste. 1999. The Green Triangle Eco-Industrial Park Proposal. New Haven, Connecticut: Yale School of Forestry & Environmental Studies.

Kincaid, Judy, and Michael Overcash. 2001. Industrial Ecosystem Development at the Metropolitan Level. *Journal of Industrial Ecology* 5 (1): 117-126.

Lowe, E. A., S. R. Moran, and D. B. Holmes. 1995. Fieldbook for the Development of Eco-Industrial Parks. Oakland, California: Indigo Development Company.

Maxwell, Joseph. 1998. Designing a Qualitative Study. In *Handbook of Applied Social Research Methods*, edited by L. Bickman and D. Rog. Thousand Oaks, California: Sage Publications.

Miller, G. Tyler, Jr. 1994. *Living in the Environment: Principles, Connections, and Solutions.* Belmont, California: Wadsworth Publishing Company.

Porter, Michael. 1995. The Competitive Advantage of the Inner City. In *On Competition.* Cambridge: The Harvard Business Review Book Series.

Porter, Michael. 1998. Clusters and the New Economics of Competition. *Harvard Business Review* (November-December): 77-90.

Porter, Michael, and C. van der Linde. 1995. Green and Competitive: Ending the Stalemate. *Harvard Business Review* (September-October): 120-134.

The Symbiosis Institute. Industrial Development Council., Kalundborg, Denmark. http://www.symbiosis.dk/tsi_uk.htm.

U.S. EPA (Environmental Protection Agency). 1999. *Tools for Eco-Industrial Development Planning*, Version 1.3: US Environmental Protection Agency, Urban Economic Development Division.

UN University. 2002. *Zero Emissions Research Initiative.* http://www.ias.unu.edu/special/zeri.cfm.

Part I: Tools From Industrial Ecology

Yale University Electronics Recycling 1998

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ABSTRACT
The objective of this report is to track the acquisition, use, and discard of computer hardware in the Yale University system and make recommendations for how the university can optimize computer recycling. Computer recycling provides an important environmental service by reducing waste and promoting industrial ecology and sustainable commerce. The proper disposal of electronic waste can prevent the dissemination of harmful toxins contained in hardware, such as lead, mercury, cadmium, and chlorinated plastics.[1]

An estimated 79 million computers worldwide were retired from their primary use by 1996, according to the Gartner Group. This year, in 1998, another 31 million PCs will join them, and by 1999 the number will climb to upwards of 42 million. Organizations within the United States are assessing the feasibility of computer recycling and implementing programs. Academic institutions, such as education and research centers, have taken the lead in recycling computer hardware. Computer recycling is an environmentally friendly and crucially necessary growth industry that can be successfully pursued at Yale University. Results indicate that Yale can double the number of computers going to Yale Recycling within the next academic year.

COMPUTER RECYCLING IN THE UNITED STATES

Computer recycling closes the recycling loop and improves economic efficiency as semiconductors, metals, plastics, and other materials are recovered and reused. As an added bonus, computer recycling could prove a profitable venture within the next 2 to 3 years, and will most definitely prove profitable within 5-7 years. According to Colleen Mizuki, an electronics recycling expert, "Of all consumer electronic products, the greatest recyclable value is found in computers" (Mizuki 1996).

Personal computers are more and more deeply integrated into our lives as they find their niche in homes, offices, and classrooms. On average, computers become obsolete and are replaced every four years, filling up warehouses and recycling trucks at an astonishing rate. Monitors have an operating life of 12 years (Mizuki 1996) and may be prematurely discarded. It is estimated that roughly 14 to 20 million computers are retired each year in the U.S., according to a 1995 Tufts University thesis (Dillon 1998). This same study estimates that

[1] The electronics industry uses virtually every type of plastic, including polymeric vinyl chloride (PVC) – a dioxin source when incinerated –, copolymer acrylonitdie-butadiene-styrene (ABS), and polystyrene (PS). Many resins are also used, such as epoxies.

nearly 75% of discarded computers are simply stockpiled ("closet-filled"), taking their place on obscure shelves, under Ping-Pong tables, in unused offices, and in hallways. Only 10 to 15% of them will be reused or recycled and 15% end up in landfills. Another study shows that 65% of corporate computers simply become closetfill, 15% are trashed, scrapped, or recycled, 15% are resold, and the remaining 5% are shipped off to schools, charities, or non-profits.

Businesses are starting to understand the value of refurbishing and recycling scrap. In the last few years, thousands of computer reselling and recycling outfits have started up around the country, according to a recent Rand Corporation report. The New York Times notes that 2.4 million used computers were resold last year (Goldberg 1998). Leasing companies such as Comdisco (www.comdisco.com) have average contracts that last less than three years. As a result, they are already starting to sell off old Pentiums by the thousands. Another company, The Boston Computer Exchange, has sold used machines since 1982. As the first used PC broker in the United States, the Exchange is now one of the nation's largest, with annual sales of $36 million. Onsale (www.onsale.com), another reseller, handles as much or more in live auctions over the Net (Parks 1997).

COMPUTER RECYCLING AT YALE UNIVERSITY

The purchase, use and disposal of computers is decentralized at Yale. Each department or program acts independently, but they all depend upon Yale's Information Technology Service (ITS) for hardware and software support.

The Yale community operates an estimated 12,000 computers, used by the students and faculty.[2] The average turnover rate is four years, which means that each year, up to 3,000 computers need to be redistributed. That number is growing as Yale continues to "computerize." As a result of Project X – Yale's initiative to upgrade University-wide financial and human resources computer systems – even more computers would be exiting from Yale in the short term as Macintosh computers are replaced with the standard Dos/Windows operating platform. These estimations imply that the Yale computer recycling program could significantly increase the number of computers recycled.

Some of these computers are re-allocated within departments, some are stored in closets (closetfill), and others are discarded. Last year (1997), the Yale Recycling Club, an undergraduate student organization sponsored by Yale Recycling, collected and transported 6.3 tons of defunct computer hardware (~127 computers, see Table 1) to a local computer recycler. In effect, Yale sells its defunct hardware at 5 cents a pound.

[2] By computer, we mean a CPU, monitor, and keyboard. Associated peripherals, such as printers, are also recycled.

Table 1 Computer Weights

I. Average Weight of a personal computer (PC) by material content

Materials	Weight (pounds)
Plastics	25
Metals	25
Ceramics	10
Total	60

Note: The Yale Recycling Club did not perform a count on the number of computers recycled in 1997. The average computer weighs 60-100 pounds. We estimate that Yale recycled 127 computers (6.3 tons divided by the conservative estimate of 100 pounds per computer).

II. Average Composition of a PC (percent by weight)

Computer Component	Percent by Weight
Printed circuit board	10
Cathode tubes	29
Cables	5
Plastics	23
Other	33

Source: OECD, Washington: Waste Minimization Workshop

Our research indicates that out of 3,000 computers in need of relocation, 2,000 enter the waste stream each year. The Yale community closetfills roughly 50%, dumps 38.7%, recycles 6.3%, and donates 5% of the waste stream. Yale has an estimated 2,000-3,500 closetfilled computers throughout its campus, taking up valuable storage space.

According to Cyril May, recycling of computers has grown tremendously during the 8 years he has worked as Recycling Coordinator for Yale University. During the early 1990s there was little interest in recycling the hundreds of computers discarded from the University every year. The first solicitation that Mr. May received was from a businessman who would accept "dead and dying" computers for a small charge. Now several computer recyclers are operating in the Connecticut area and Yale Recycling, the undergraduate student organization, is able to sell defunct computers at 5 cents/pound (May 1998).

During the early 1990s there was little interest in recycling the hundreds of computers discarded from the University every year. Now several computer recyclers are operating in the Connecticut area and Yale Recycling, the undergraduate student organization, is able to sell defunct computers at 5 cents/pound (May 1998).

The scale of these cybermorgues ranges from that of Computer Recycling and Refining of Branford, staffed only by full-time owner Armand LaCroix and some part-time help, to Absolute Recycling of West Haven, an operation that dwarfs the average Home Depot, with a 500,000 square foot warehouse. The care it gives to each machine, however, cannot compare with that given by the smaller operation. Even Yale's computer outflow may be too small and heterogeneous to work effectively with Absolute Recycling.

Last year Yale Recycling delivered 6.34 tons of computers to Computer Recycling and Refining of Branford. Computer Recycling and Refining, Inc.

evaluates each machine: working machines are resold or donated, malfunctioning machines are fixed or have useful components removed, and the truly dead machines are ground up for precious metals. Lead-containing Cathode Ray Tube (CRT) monitors are out-sourced for disposal overseas, a potentially problematic practice, as regulations abroad may not protect the workers and environment. Most computer recyclers charge a fee ($3-$10) to recycle CRT monitors in line with adequate environmental standards (Mizuki 1996).

Yale University makes direct donations of functioning computers to local non-profits. Daisy Rodriguez, Assistant Secretary for Community Relations in the Office of New Haven Affairs, finds homes for working Yale computers in non-profit organizations including schools, libraries, and community groups (Rodriguez 1998). Similarly, Bill Sacco, Peabody Museum Photographer and "Mr. Fixit" for the Yale Macintosh Users' Group (YMUG), donates old Macintosh computers, many of which he has personally repaired, to worthy causes. During the summer when the program has additional student helpers, it is able to funnel working computers directly to area organizations (Sacco 1998). The Yale Recycling Club delivers many of these computers.

As a result of this study, the University has established standards described below for choosing when a computer should be recycled or donated.

Yale Recycling asks the community to firmly attach a sign to computers that are left for pickup to indicate whether they are "dead," malfunctioning, or in working order. This helps tremendously in the triaging process. The only times when the program is unable to provide collection services are winter recesses – typical student "crunch" periods when student workers are too busy working on their own computers to recycle others – and when the truck goes in for repairs. Most of the computers collected, however, are either defunct or too far gone to warrant repair for donation.

Computer recycling benefits the environment, improves material flow efficiency, educates students, and establishes Yale University as a leader in applied industrial and environmental services.

For every pound of computer hardware diverted from the garbage bin, Yale saves on its trash disposal or tipping fees. It gives these savings to the student Yale Recycling Club to offset their labor costs. We estimate that Yale realizes $3.00-$3.50 in avoided cost for each computer that is recycled. Valuable resources, such as the precious metals and other computer components are recovered, rather than lost in the waste stream. Computer recycling benefits the environment, improves material flow efficiency, educates students, and establishes Yale University as a leader in applied industrial and environmental services.

PROJECT GOALS

To fulfill our research project objective, we established the following four goals:

- To assess and document the current Yale Computer Recycling Program (YCRP). This includes establishing a stock/flow diagram, developing financial balance sheets, and gathering information from students, faculty, administrators, and staff.

- To assess and document the movement of computers through Yale. Computers flow through Yale in a highly decentralized manner. We investigated this flow using individual inquiries of staff, administrators, and faculty, and an email survey.
- To specify five potential options for the YCRP and analyze their relative merits.
- To offer short-term and long-term recommendations to the University regarding YCRP.

PROJECT METHODOLOGY

We surveyed the literature, on-line and in print, for background information. Many individuals in the Yale community were contacted to acquire information about computers and computer recycling at Yale. Cyril May, the Yale Recycling Coordinator, served as our primary staff contact, providing us with detailed information. We also contacted local area computer recycling business managers (Bruce Cafasso, Armand Lacroix, and others), a representative of the University of Massachusetts computer recycling program (John Pepi), and a representative at Tufts University (Patty Dillon), to ascertain the regional computer recycling market. We visited and submitted a draft Statement of Work (SOW) to a local area business, Absolute Recycling Inc., which potentially could offer Yale a higher rate per pound for computers. We contacted environmental regulators at the Connecticut Department of Environmental Protection (DEP) and EPA. We contacted experts to get an up-to-date idea of the state of computer recycling and computer leasing (a viable option) across the nation; Colleen Mizuki at the Microelectronics and Computer Technology Corporation (MCTC), a trade-sponsored corporation, provided abundant and detailed information.

In order to gauge the stocks and flows of computer hardware, we first garnered estimates of computer stocks at Yale from Philip Long at Yale Information Technology Services (ITS). We obtained permission from Daniel Updegrove, the Director of ITS, to email a survey questionnaire to the Super-Users Group (refer to Appendix I). The Super-Users Group consists of computer coordinators in Yale's individual departments, many of which act as computer purchasers. ITS maintains a Super-Users email list, with 236 subscribers. They document purchases and disposal of computers.

Forty individuals replied, representing 45 Super-Users or 20% of the list. We extrapolated total figures for Yale by multiplying the survey responses by five. We also contacted ITS, Yale Recycling, and other computer-related departments for information. The Yale Purchasing Department and Microcomputer Support Center (MCSC) was contacted to determine the flow of computers into Yale through personal purchases and departmental procurement.

PROJECT RESULTS

Fifty-five percent of the Computer Recycling Questionnaire respondents did not know that Yale Recycling picked up and recycled computer hardware. Respondents indicated that computers are replaced once every four years, on average. Figure 1 demonstrates the fate of non-recycled computers in the past four years. By extrapolation, the survey accounts for a total of 1,430 computers being closet-filled, retro-fitted, donated, or otherwise discarded. Many computers probably remain in departments as hand-me-downs to employees and graduate students.

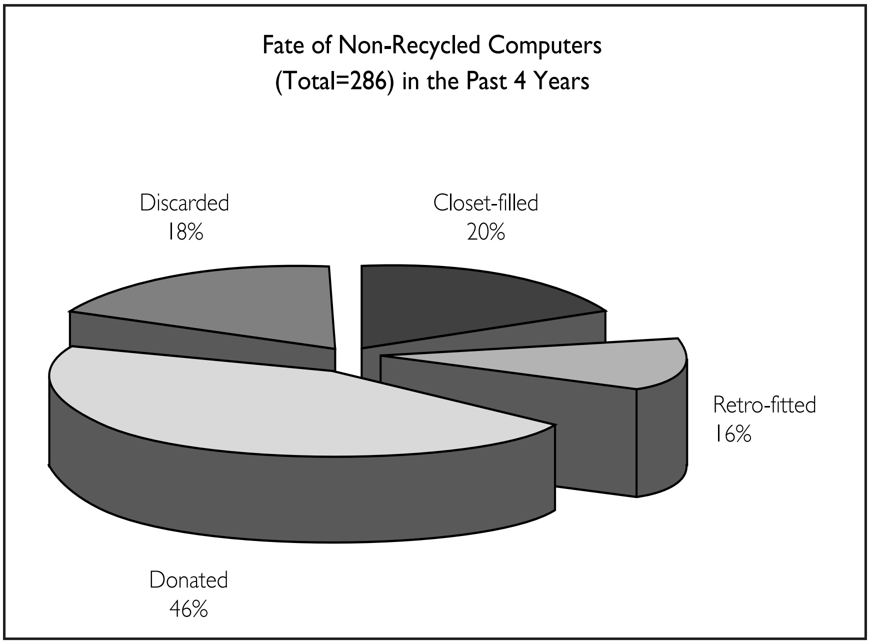

Figure 1 Fate of Non-Recycled Computers in the Past Four Years

According to Long's estimates, 85-90% of undergraduates own machines, representing roughly 4,600 computers. Another estimated 2,400 computers are owned by graduate students. Graduate and Professional School student ownership is harder to gauge (ownership probably varies considerably by course of study from 100% in Yale School of Management to, say, 40% in the Schools of Art or Drama). Additionally, there are roughly 350 computers in clusters throughout the University. Further computer ownership estimates are: 1,600 computers for management and professionals; 800 operated by clerical and technical employees, 560 operated and an additional 1,500 machines in use by faculty and research staff. Long's estimate comes out to a total of 12,000 computers. This does not include computer support hardware, such as printers and scanners (Long 1998).

Survey respondents reported that their departments operate 2,838 computers. This suggests that Yale, as a total, operates 14,200 computers. The entire Yale community, including personal computers used by students and faculty, probably ranges between 12,000 to 14,200. If computers are replaced at a rate of one in four per year, then we estimate that Yale departments will need to recycle, donate, or dispose of between 3,000 to 3,500 computers annually. Most departments re-assign computers internally and personal users tend to keep their own computers, so we have lowered this estimate of computer outflows that Yale will need to handle. We set the value of closetfilled and discarded computers at 2,000 per year in our analysis (an estimated 60-100 tons of CPUs and monitors annually). The handling load increases when considering computer peripherals such as scanners and printers.

Gail Tarantino of the Purchasing Department mentioned that her department purchases 2,500 computers annually (Tarantino 1998). In addition to this, the Microcomputer Support Center, which is the department that provides pre- and post-support services on computers coming into Yale, buys approximately 2000 computers (desktops and laptops) a year.

Recycling depends upon the recyclability of the product that is purchased; more modular and recyclable designing on the part of manufactures could improve the profits generated from computer recycling in the long-term.

It is difficult to determine the number of computers coming in through schools and departments. While most schools and departments procure computers through the purchasing department and MCSC, a few bought them through such vendors as Micron, Gateway, Dell, Databyte, and direct ordering. Survey respondents indicated purchasing 363 monitors, 349 CPUs, 59 laptops, 125 printers, and 26 scanners in the past year.

Recycling depends upon the recyclability of the product that is purchased; more modular and recyclable designing on the part of manufactures could improve the profits generated from computer recycling in the long-term. When asked if computer recyclability would be a consideration when purchasing, 60% responded in the affirmative, although many individuals emphasized the primary importance of usability and performance.

The fact that only about half of Yale's computer coordinators knew about computer recycling reinforces our conclusion that Yale can double the amount of computer hardware recycled in the next three years. We include in our recommendations ways in which computer recycling can be publicized.

The compiled stock/flow diagram, (Figure 2) compiles the flow of computers through Yale. This is the first step in any effective computer recycling/ hardware management program.

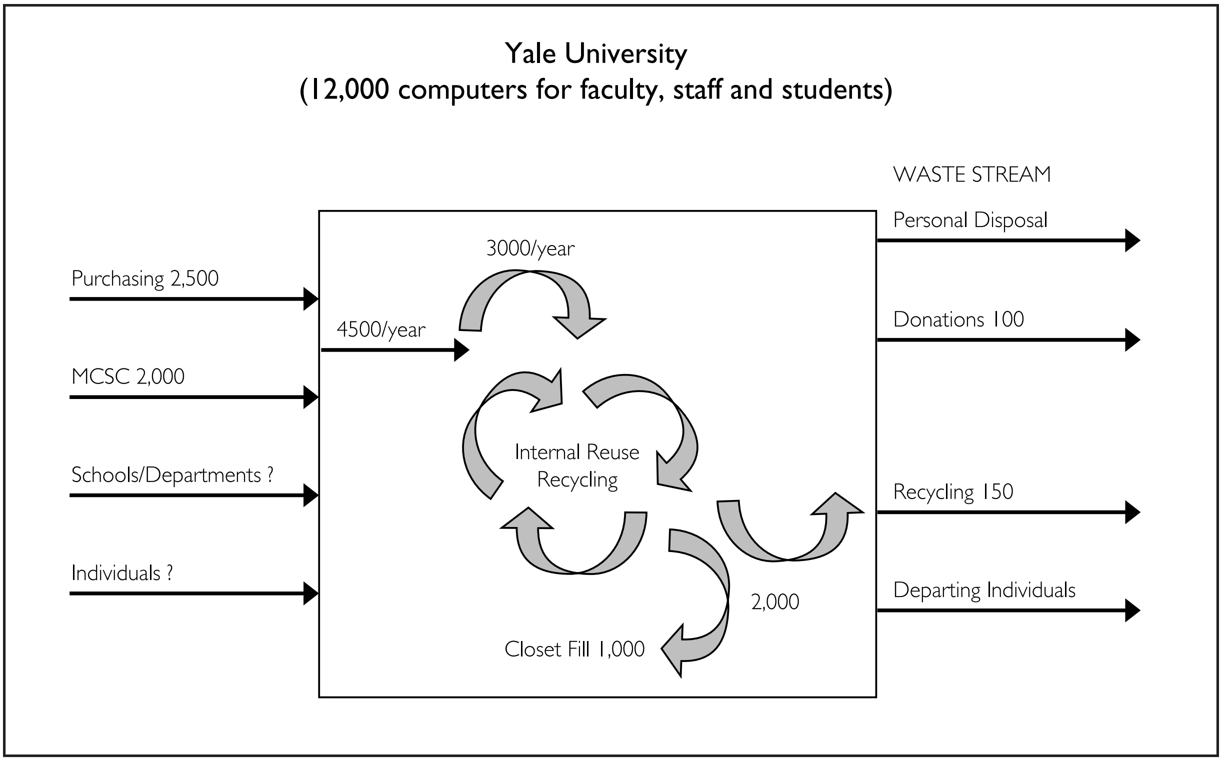

Figure 2 University Electronics Recycling

COMPUTER RECYCLING MARKET IN CONNECTICUT AND NEW ENGLAND

As part of our research, various recyclers in the New England area shared with us their perspectives and recent experiences related to the computer recycling business. The market is nascent and volatile. In general, most companies charge a management fee for overseeing a computer/electronics recycling program. Establishing a formal recycling program with some of these companies could involve fees for services, such as inventory, monitor dismantling, miscellaneous equipment, and transportation.

There are plenty of smaller players at this point in the food chain: scrappers and recyclers who disassemble dead computers and separate them into circuit boards, plastic, and steel. Sometimes they grind up whole machines and separate them into ferrous and non-ferrous material. The steel cases go to a metal recycler. Cables go through a refining process that removes the insulation and recovers the copper. The plastic is often landfilled or incinerated as fuel.

PROPOSED OPTIONS

There are five general options that Yale University can adopt when considering its computer recycling program. Some are more feasible and environmentally effective than others.

- Option 1: Stop Recycling
- Option 2: Continue Program with Computer Recycling and Refining Inc.
- Option 3: Switch Service Provider to Absolute Recycling
- Option 4: In-house Electronic Recycling
- Option 5: Explore Computer Leasing

Option 1: Stop Recycling
Aside from being environmentally negligent and a potential public-relations fiasco, ceasing to recycle computers would place Yale at a disadvantage as the computer recycling market develops and/or if CRT monitors become regulated for their lead content. Yale would pay an extra $476.55 in waste disposal fees that it avoids by recycling.

Option 2: Continue Program with Computer Recycling and Refining Inc.
Yale University receives 5 cents per pound for computer hardware it recycles through Computer Recycling and Refining Inc. and saves money in avoided waste tipping fees. Last year, Yale Recycling recycled 6.34 tons, grossing $1,108.55. The Yale Computer Recycling Program (YCRP) pays student wages at $6.95 an hour, and $120 for the trailer space it uses to store computers before they go to Branford, costing $3,830. In the academic year 1996-1997, Yale paid $2,721.45 to recycle its computers. Table 2 compares the current operating balance sheet for the YCRP with a balance sheet if the number of recycled computers were doubled. We assumed a 1:1 linear relationship between number of computers and work hours. Doubling the number of computers recycled is a realistic goal of this study.

Computer recycling is unlikely to be profitable within the next 4 years; however, as computers are designed for end-of-life recycling and as the computer recycling market develops, the price per pound of computer hardware should increase.

The largest cost ($3,590) for 1996-1997 went to paying student wages for 528 hours of work. A portion of these hours went to recycling non-mandated plastics, another project of the Yale Recycling Club. While our group is investigating the feasibility of higher rates for Yale's computer hardware through another company (Absolute Recycling), 5 cents an hour is the putative industry standard in the near future (see Table 2). In order for YCRP to break even with current costs, it would have to sell its defunct hardware at $0.25 per pound, a five-fold increase over the current rate. In the short term, for YCRP to be profitable, it should cut costs.

The most effective way for YCRP to cut costs is to reduce the number of student hours it takes to pick-up and deliver computer hardware. With a projected doubling of computers, YCRP would have to reduce the number of work hours from 1,000 to 302 to break even, at the current wage of $6.80 per hour. Student workers report that they could not effectively handle and transport the hardware load in 1/3 the time. However, when we proposed instituting a definite pickup schedule for different areas of Yale University for improved efficiency, Cyril May indicated that this could reduce the number of work hours.

Table 2 Computer Recycling Budget (actual vs. projected)

	Current Recycling Program A		Option 2 with Doubling of Computers B		Option 2 with New Wage and Doubling of Computers C
Wage	$6.80	Wage	$6.80	Wage	$4.07
Hours/week	10	Hours/week	20	Hours/week	20
Hours/year	528	Hours/year	1000	Hours/year	1000
Total personnel/year	$3,590.00	Total personnel/year	$6,800.00	Total personnel/year	$4,070.00
Rental of trailer/year	$85.00	Rental of trailer/year	$85.00	Rental of trailer/year	$85.00
Rental of parking/year	$35.00	Rental of parking/year	$35.00	Rental of parking/year	$35.00
Total storage/year	$120.00	Total storage/year	$120.00	Total storage/year	$120.00
Total expenses/year	**$3,830.00**	**Total expenses/year**	**$6,920.00**	**Total expenses/year**	**$4,190.00**
Sale of Scrap		Sale of Scrap		Sale of Scrap	
Tons recycled/year	6.34	Tons recycled/year	12.5	Tons recycled/year	12.5
Price paid/ton/year	$100.00	Price paid/ton/year	$100.00	Price paid/ton/year	$100.00
Income	$634.00	Income	$1,250.00	Income	$1,250.00
Other Income (avoided fees)	$476.55	Other Income (avoided fees)	$853.10	Other Income (avoided fees)	
Total income/year	**$1,108.55**	**Total income/year**	**$2,103.10**	**Total income/year**	**$2,103.10**
Total expenses/year	$3,830.00	Total expenses/year	$6,920.00	Total expenses/year	$4,190.00
Net income/year	**($2,721.24)**	**Net income/year**	**($4,826.90)**	**Net income/year**	**($2,086.90)**

Another way for YCRP to reduce operating costs due is to pay students through the Work Study program. Computer recycling is a valid community service, because the same service transports computers for donation to the community. Computer recycling also shows environmental and social responsibility. Students would actually receive a higher wage, $8.15 per hour, with Yale Recycling paying for 1/2 or $4.07 per hour. In order for YCRP to break even, the number of work hours would have to be reduced to 516 (from an estimated 1,000) or the rate per pound of computer hardware would have to increase to 13 cents per pound (a 2.6 fold increase). These are more realistic goals. If Yale were to receive 8 cents per pound and YCRP work-study student employees worked 713 hours, YCRP would break even, assuming a doubling of the number of computers recycled.

Recycling of computers positions Yale very well for the future. Computer recycling is unlikely to be profitable within the next 4 years; however, as computers are designed for end-of-life recycling and as the computer recycling market develops, the price per pound of computer hardware should increase. Computer recycling experts, and our research, indicate that computer recycling will be profitable within the next seven years. Yale could realize returns earlier if it continues to progress. Yale also positions itself to avoid future costs, as waste tipping fees are likely to increase. Additionally, should the government start to regulate CRT monitors due to their lead content, Yale would already be in compliance.

Option 3: Switch Service Provider to Absolute Recycling

Seeking an alternate service provider is another option Yale University should consider. After researching recycling service providers in the New England Area, we decided to explore establishing a relationship with a large-scale recycler. Conveniently located in West Haven, Absolute Recycling, Inc. represents an attractive option, given the breadth and scale of recycling services it provides.

As a full service recycler, Absolute Recycling, Inc. offers several advantages over the current small-scale program with Computer Recycling and Refining Inc. First, Absolute's access to its own fleet of vehicles and trailers would reduce Yale's administrative and economic costs associated with the rental of trailers. Second, Absolute offers several transportation services, one of which hauls trailers to the client's facilities. This service would reduce the number of student work hours required. Finally, other electronic and medical equipment could be eventually considered for recycling given the breadth of services Absolute Recycling, Inc. provides.

The Sales Manager, Bruce Cafasso, was our primary contact at Absolute. We were able to visit the company's 500,00 square foot facility one afternoon. Mr. Cafasso mentioned that the value of recoverable computer components varies depending on the make, model, and volume of computers recycled. Volume determines price given that selling 10,000 of a particular component is easier than finding a buyer for limited quantities. He also mentioned that the more expensive the component during manufacture, the more valuable it is at the end of life (e.g., the processor and the display); furthermore, the more modular a component, the less costly it was to recover, as fewer hours were required for disassembly (Cafasso 1998).

Volume determines price given that selling 10,000 of a particular component is easier than finding a buyer for limited quantities.

Although Absolute cannot be compared to the typical scrap dealer, it performs similar activities. The CPU's are first scavenged for usable chips; then, the remaining circuit boards are sent to a smelter for the recovery of precious metals, such as gold and silver. Plastic reclamation presents a more difficult problem since the plastics are often in the form of multi-resin laminates or have bits of metal embedded in them. The plastics market, which is cost driven, places a higher value on plastic that is uncontaminated. One computer manufacturer, IBM, has recently begun to address this problem by using more single-resin polymers. Regarding monitors, Mr. Cafasso noted that many are sent overseas to countries in Africa, Asia, and Latin America, where worker compensation is not considered.

An important distinction between Absolute and our current recycler is the method of payment. Yale's current recycler offers a price based on tonnage – 5 cents/pound or $100/ton. Absolute, however, offers a price based on a computer number and type. Mr. Cafasso stressed that computer components, as commodities, obtain varying prices on the market. As a result, Mr. Cafasso recommended that we list the type of equipment that Yale would consider recycling. Hence, we drafted a Scope of Work (SOW) (see Appendix II) and sent it to Absolute Recycling to determine whether a higher value could be obtained for recycling obsolete computer equipment. Based on the SOW, Absolute would determine its current value on the market. If Yale were to strongly consider implementing the pilot project in the future, the SOW and other documents listed under the in-house recycling option could be used as a framework to further the process. Prior to initiating a program with a new service provider, Yale should ensure that the company is completely permitted.

Yale's present computer outflow is relatively small and too heterogeneous to represent a profitable opportunity for Absolute Recycling. Absolute is more accustomed to dealing with large business corporations across the country, such as IBM. Therefore, this option should be examined in the medium term. If our predictions are correct, the Yale Computer Recycling Program should be able to significantly increase the number of computers recycled through the program. A larger flow of computers would represent a more significant commodity for Absolute Recyling. More accurate planning numbers could also be determined if Yale established better tracking systems for recycled computers.

Given that computers and other electronic equipment contain valuable materials and some components can still be put to use, Yale could start an in-house recycling program, whereby pieces of electronic equipment could be triaged and their parts segregated and sold separately for a profit.

Absolute Recycling also expressed interest in participating in future Request for Proposals involving the recycling of commodities such as paper, cardboard, and wooden skids. By increasing the number of commodities recycled through Absolute, Yale could obtain a higher rate of return on its recycling program.

Option 4: In-house Electronic Recycling

This option would involve disassembling computers and other electronics in-house at Yale instead of having to sell at a bulk price as currently done through Computer Recycling and Refining Inc. Computer Recycling and Refining Inc. pays $0.05/pound for recycled computer components and salvages the parts for valuable materials (Computer Recycling and Refining, Inc. 1998). Given that computers and other electronic equipment contain valuable materials and some components can still be put to use, Yale could start an in-house recycling program, whereby pieces of electronic equipment could be triaged and their parts segregated and sold separately for a profit. This involves determining the value of recycled components.

Electronic recycling is a relatively new business and we have yet to understand the economies of scale for this sector. Profitability in recycling electronics is highly dependent on the market value of recycled components. We tried to estimate the market value of different components through interviews with various recycling companies, particularly in the New England area, but it was difficult to obtain specific market values for these goods. The recycling market seems to be affected by a complex array of demand and supply factors.

What Yale could think of doing under this option could be something similar to what the University of Massachusetts (UMass) is currently undertaking. In 1993 Marc Fournier, Waste Manager of UMass, started a disassembling line for electronic equipment called the Intermediate Processing Facility (IPF) as a way to divert additional materials from the university waste stream. He identified a local company, Electronic Processing Associates Inc. (E.P.A, Inc) in Lowell, Massachusetts, and with its help designed a de-manufacturing unit to determine what materials were marketable. According to John Pepi of the University of Massachusetts Waste Management Office, an intermediate on-campus organization called PC Maintenance salvages the electronics for usable components before they actually get to the IPF. The de-manufactured components from the IPF are eventually sold to local recycling companies by bids (Appendix III). The IPF employs students who collect used computers and other electronics from both on the university campus and off (local municipality, organizations, and individuals). A fee of $5.00 is charged for every monitor, $4.00 for other computer components, and $1.00 for keyboards and other small accessories collected outside the campus (Pepi 1998).

The capital cost for establishing the de-manufacturing unit was only $1,000. The facility uses a 13,000 square foot space owned by the University and uses simple equipment such as air-powered screw drivers and other hand tools. The operating cost of the unit is $58,900, which basically covers student labor ($7.00 per hour). The revenue generated from the operation is $4,000. Fifty-five percent of the finance comes from the University and 45% comes from the sale of electronic components to E.P.A, Inc.

The facility at UMass is the largest publicly-owned electronics recycling and processing facility in the United States. By starting such a program, UMass has been able to create new work study jobs for its students, generate revenues from the sale of computer components, create new markets for materials not recycled previously, divert hazardous materials from landfills, and reduce expenses in waste disposal. UMass estimates that recycling and reusing electronics is approximately $10.00 cheaper per ton than landfill disposal ($55.00 in Massachusetts vs. $70.00 in Connecticut).

The facility at UMass is the largest publicly-owned electronics recycling and processing facility in the United States. By starting such a program, UMass has been able to create new work study jobs for its students, generate revenues from the sale of computer components, create new markets for materials not recycled previously, divert hazardous materials from landfills, and reduce expenses in waste disposal.

However, according to Mr. Pepi, the program at UMass is actually not profitable. He said that the revenue generated from the sale of electronics merely offsets the cost of operating the facility (collection, labor, hauling, electricity, etc). But Mr. Pepi was very optimistic about the program despite the poor rate of return. The authors of this project share Mr. Pepi's view that although the program is not profitable, it is worth pursuing, especially since UMass is a non-profit organization.

There are major environmental benefits in recycling and reusing electronics. These benefits are difficult to quantify and therefore are left out of the cost benefit analysis. There is also the salient issue of liability. Electronic equipment is comprised of various heavy metals (e.g., lead, cadmium, mercury) and chemicals that are highly toxic to humans and the environment, and therefore increase the risk of being a potential health and safety hazard if disposed of improperly. Recycling and reusing electronic equipment reduces the risks of future liability of an organization that is involved in the disposal of such wastes.

Based on the above discussion, we feel that the establishment of an in-house de-manufacturing unit similar to the one at UMass would be a feasible option. The following are some of the pros and cons of this option for Yale University. As Project X continues to publish standards for Yale's departmental desktops, the number of computers dumped, abandoned, or picked up by the Yale Recycling Program is going to increase as users are forced to upgrade. This means most computers will either go to Computer Recycling and Refining Inc. as it is now, or will be donated or passed down to staff. Eventually, however, all these computers will be trashed or recycled. Hence an in-house recycling program would be a feasible option. Computers are already piling up in basements and hallways and causing fire hazards and obstacles to exits. Yale is losing money by having to 1) rent trailer space to store dead computers, 2) pay students to move the computers from one site to another, and 3) dump the computers for a nominal return. Conversely, Yale would save money by instituting a system whereby the computers were picked up, triaged, and moved out.

With the growing recognition of the concept of industrial ecology (and therefore design for environment), the electronic industry will, in the near future, design products such that de-manufacturing is easier and less time consuming.

It is also possible to donate usable computers and equipment to the community to enhance town-gown relations. Additionally, students have expressed their interest in having a computer recycling program as part of the Green Plan (the University's environmental plan). Such a program not only provides employment for students but also provides training in computer de-manufacturing.

With the growing recognition of the concept of industrial ecology (and therefore design for environment), the electronic industry will, in the near future, design products such that de-manufacturing is easier and less time consuming. Computer recycling will also reduce pressure on virgin materials and therefore help in conserving natural resources (e.g., energy and reduction in waste generated). Finally and most importantly, by implementing an in-house de-manufacturing unit, hazardous metals and chemicals will be diverted from the normal waste stream, thereby eliminating future liability cost to Yale. Therefore, an in-house recycling program is an option that Yale University could consider in the near future.

There are disadvantages in establishing an in-house recycling unit at Yale, however. Recent changes in technology in the electronics industry have reduced the use of valuable waste materials. Therefore, there is not as much incentive to recycle. However, as resources get scarce, the value of current computer components will increase. Given this future trend, it is likely that recycling will still be a profitable business. Space will be a problem for Yale. Yale will have to rent a space to store all the dead and unused computers. The location should be accessible to delivery trucks.

Yale may want to explore incubating or inviting the establishment of an electronics recycling company in Science Park as a viable alternative to an on-campus departmental facility.

Currently, there are no federal or state regulations governing the recycling of electronics. In the absence of stringent regulation, there is less incentive to recycle and reuse. In addition, the current computer recycling market is not very well established, and therefore it is difficult to predict the costs and benefits of recycling.

Option 5: Explore Computer Leasing

Leasing is quickly becoming the procurement method of choice for many organizations. According to the IBM Credit Corporation, more than 50% of computer equipment in the United States is acquired through leasing programs. Leasing offers several technological and environmental advantages.

The first advantage offered by leasing is that it hedges against obsolescence. Experts note that due to rapid technological advance, a computer can lose up to 80% of its value within a year of purchase. Thus, in order for Yale to maintain the most current computer technology, it would be more financially efficient to establish a leasing program, which allows the option of system upgrades. When a better system comes out in the middle of the contract, some leasing plans offer the option of allowing upgrades on a timetable that would fit the organization's needs. Any upgrades would entail additional costs, but those costs would most likely offset the costs of purchasing and disposing of computers every 3-4 years. Leasing also offers the advantage of flexible contract terms.

Experts note that due to rapid technological advance, a computer can lose up to 80% of its value within a year of purchase. Thus, in order for Yale to maintain the most current computer technology, it would be more financially efficient to establish a leasing program, which allows the option of system upgrades.

Environmental advantages are also important to consider. Yale University would not have to worry about the potential hazards associated with the disposal of computers, as they would be returned to the manufacturer or leasing firm at the end of the contract term. Hallway and basement space that is currently occupied by obsolete computers could become available for other purposes and pose less fire hazard risk.

More importantly, leasing promotes the recycling and reuse of computers and their components. As computer leasing becomes popular, a larger number of leased computers of the same models and of similar quality would be returned to computer manufacturers. This characteristic of leasing could reduce the contamination problem of recyclable materials. The manufacturer also could take advantage of the economy of scale. By incorporating design for environment (DfE), computer manufacturers could design computers so that they are more easily dismantled and recycled, or upgraded and reused. For example, Dell Computers started a leasing program a couple of years ago. As computers come off of lease, they are resold (often with some upgrade) or de-manufactured and recycled for material recovery. As increasing numbers of leasing contracts come to term, computer manufacturers will need to place greater emphasis on end-of-life considerations. Rapidly changing technology is a challenge faced by the computer manufacturing industry.

Yale University could take advantage of its purchasing power to obtain better leasing rates if the program were administered through a single channel. Preferably, the leasing program would be administered by a central organization on campus, like the Micro Computer Support Center. The MCSC has examined leasing options in the past, but was unable to pursue them due to legal issues surrounding Yale's non-profit status. However, the MCSC noted it would be willing to reconsider leasing, if presented with new options.

Ownership mentality is one obstacle to a leasing program that needs to be overcome. Since most people tend to place higher value on owning personal goods, such as computers, it might be more difficult to persuade departments and individuals to give up ownership rights and switch to leasing. However, a flexible leasing program might overcome this ownership tendency as the reward of upgraded technology outweighs the non-ownership costs.

RECOMMENDATIONS

The computer recycling program at Yale University has successfully evolved in the past three years to fill a much needed niche. With this report, we hope to guide Yale towards making computer recycling profitable and more effective, in terms of the number of computers recycled, recycling efficiency, and environmental performance. The demand for computer recycling is growing and it is currently met by an unstable supply, mostly because computers are not designed with dissassembly in mind. Manufacturers have not traditionally thought about the end-of-life of their products, or the potential value of re-using or breaking down defunct hardware – a recurrent theme in the modern-day effort to integrate ecological principles of materials flow and sustainability into the human system. Computer recycling is a growth industry.

The best option in the short-term is Option 2 above, to continue the current computer recycling program, with some improvements. The three key components in the short-term (1 year) are (a) awareness and publicity (b) reduction of student labor hours per computer recycled and (c) better tracking of computer hardware through the Yale system.

According to our survey, less than half the respondents knew that Yale recycles computers. This observation points toward the feasibility of significantly increasing the number of computers recycled, especially if a portion of the large number of closet-filled computers (an estimated 2,000-3,000) are recycled.

According to our survey, less than half the respondents knew that Yale recycles computers. This observation points toward the feasibility of significantly increasing the number of computers recycled, especially if a portion of the large number of closet-filled computers (an estimated 2,000-3,000) are recycled.

The responses of individuals to our survey demonstrated considerable confusion about the nature of computer recycling. A few respondents thought that computer recycling meant re-use by another user, not the dissassembly and sale of the component parts. The fact that people closetfill computers demonstrates an understanding of the wastefulness of throwing computers away. In other words, reflex sentiments support computer recycling, especially if it benefits Yale financially. Publicity is a crucial early step to strengthen computer recycling at Yale.

Faculty, staff, administrators, and students need to know who to call to recycle their broken or defunct equipment. Yale Recycling already publicizes and handles a heavy workload. However, we recommend that Yale Recycling (a) advertise computer recycling at the Staff Orientation Day fair, (b) put signs up at MCSC and the Repair Unit, (c) pursue a computer hardware drop-off day, and (d) investigate other publicity channels. The ITS Super-Users group could receive two standard emails per semester from Yale Recycling, one at the beginning of the semester to establish contact information, and one at the end to inform users of the progress of hardware recycling. Undergraduate Computer Assistants, university-paid troubleshooters, could also receive computer recycling contact information as a part of their yearly training.

We recommend obtaining a copy of the baseline report on electronic product recovery and recycling in the United States produced by the EPR2 Project (Electronic Product Recovery and Recycling). The baseline report addresses the volume and nature of equipment currently being recovered and recycled; the nature, size, and distribution of recycling and de-manufacturing facilities in the United States today; projections for equipment turnover in the coming decade; and the market for key materials.

We recommend that the Yale Recycling Club maintain a log-book for the computer hardware that is recycled. Finer resolution of the hardware that is going to recycling could be used to leverage better financial arrangements with recyclers in the future.

The evaluation of Option 2 (continue the current recycling program) pinpoints labor costs as the primary reason that the YCRP operates with a yearly fiscal net loss. The section above discusses this in greater detail, but it is important to reiterate that the Yale Recycling Club could take steps right now to approach profitability. However, we feel strongly that profitability cannot be the sole criterion when evaluating the merit of computer recycling, especially given the immature nature of computer recycling in general. Computer recycling clears space used up by closetfill. It also positions Yale well for future regulations and/or markets.

We recommend that the Yale Recycling Club maintain a log-book for the computer hardware that is recycled. Finer resolution of the hardware that is going to recycling could be used to leverage better financial arrangements with recyclers in the future. The School of Forestry & Environmental Studies, Yale Recycling, or another element of Yale University should continue to refine the computer hardware flow/stock diagram that we have developed.

The best option for the medium-term is Option 3. The three key components in the medium-term (2-3 years) are (a) switching the computer recycling company that handles Yale's defunct hardware (push for 8 cent/pound rate) (b) conducting further self-assessment and investigation of the external computer recycling market and (c) using Yale's stature as a premier educational institution as a forum for computer recycling and a method for obtaining advice from experts using Yale's program as a case example. We believe that in the medium-term, Yale can double the number of computers it donates to the New Haven community. The merit of maintaining the Yale Computer Recycling Program will become more apparent as the market develops and/or CRT regulations begin to accumulate.

The prevalent options in the long-term are Options 4 and 5. There are three key components in the long-term (4+ years) for computer recycling. They are (a) to establish an in-house electronics recycling program (b) to foster an electronics recycling outfit at Science Park and (c) to pursue computer leasing. Computer recycling will probably become more profitable in the long-term as design-for-end-of-life is implemented and new recyclable materials are manufactured.

CONCLUSION

In order for industrial ecology to be feasible, its methodology must be able to encompass complex products. Source materials for computer hardware are highly heterogeneous because computers are the ensemble of literally hundreds of intricately designed and manufactured products. The pace of technological change in the industry further complicates the challenge of incorporating industrial ecology concepts, such as design for the environment and product take-back-design for end-of-life. Computer recycling represents the first step in the transformation of a complicated industry into a more sustainable and environmentally responsible venture. Yale's Computer Recycling Program is already an unwitting leader in this effort. With the use of industrial ecology, Yale University can achieve far more.

REFERENCES

Cafasso, Bruce. 1998. Sales Manager, Absolute Recycling. West Haven, Connecticut. Personal communication. March to April, 1998.

Computer Recycling and Refining. 1998. Branford, Connecticut. Personal communication. March, 1998.

Dillon, Patty. 1998. Tufts University. Boston, Massachussetts. Personal communication.

EPR2 (Electronic Product Recovery and Recycling) Project. Baseline report on electronic recovery and recycling in the U.S.

Goldberg, Carey. 1998. Where Do Computers Go When They Die? Into the Attic, Under the Ping-Pong Table, But Hardly Ever Into the Trash. *The New York Times.* March 12, 1998.

Long, Philip. 1998. Information Technology Services (ITS), Yale University. New Haven, Connecticut. Personal communication.

May, Cyril. 1998. Recycling Coordinator, Yale University Recycling. New Haven, Connecticut. Personal communication. January to April, 1998.

Mizuki, Colleen. 1996. Microelectronics and Computer Technology Corporation. Austin, Texas. Personal communication.

Parks, Bob. 1997. After life: Where computers go to die. *Wired Magazine.* Issue 5.07. July, 1997. wysiwyg://23/ http://www.wired.com/wired/5.07/afterlife.html

Pepi, John. 1998. Office of Waste Management, Physical Plant. University of Massachusetts, Amherst. April, 1998.

Rodriguez, Daisy. 1998. Assistant Secretary for Community Relations in the Office of New Haven Affairs, Yale University. New Haven, Connecticut. Personal communication.

Sacco, Bill. 1998. The Macintosh User's Group, Yale University. New Haven, Connecticut. Personal communication.

Tarantino, Gail. 1998. Purchasing Development, Yale University. New Haven, Connecticut. Personal communication.

FURTHER INFORMATION

Advantage Computer & Leasing. Q&A. http://www.remarkting.com/broker_html/advcom/advqa.html

Alco Refiners. 1998. New York. Personal interview. March, 1998.

Amore, Dawn. Senior Program Leader, Environmental Health Center, A Division of the National Safety Council, Washington, D.C. Personal communication.

Compaq Capital. 1998. Website and personal communication. http://www.compaq.com/resellers/capital/smb/qa.html

Computer Recycling. http://voicenet.com/~cranmer/comps.html

Computer Recycling and Electronic Recycling. http://www.libertynet.org:80/~share/

Duncan Computer Recycling. http://www.remarketing.com/broker_html/duncan/

Efionline. 1998. Advantages of leasing. http://www.efionline.com/wlease.html

Electronics Processing Association. 1998. Lowell, Massachusetts. Personal interview. April, 1998.

Environmental Protection Agency. 1998. *Electronics Reuse and Recycling Directory.* http://www.epa.gov/epaswer/non-hw/recycle/reuse/efectdir/

Epix Internet Services. http://enviro@epix.net

Haverstock, MaryAnn N. 1998. Waste Engineering and Enforcement Department, Department of Environmental Protection. Hartford, Connecticut. Personal communication.

Household Hazardous Waste Management News. High Tech Trash. October, 1996.

International Computer Financing, Inc. 1998. Advantages of Leasing Equipment. http://www.computer.financing.com/why.html

MacRae, Katy. Computer Repair Unit, Yale University. New Haven, Connecticut. Personal communication.

Meyer, Everett. 1998. Editor, Yale Green Plan, Yale University. New Haven, Connecticut. Personal communication.

PEP Computer Recycling. 1998. http://www.pepsite.com/Recycle/Maryland.html

Perez, Javier. 1998. Micro Computer Support Unit, Yale University. New Haven, Connecticut. Personal communication.

Preserving Resources through Integrated Sustainable Management of Waste. http://www.wrfound.org.uk/wrftbmrf.htm1#top

Share the Technology, Computer Recycling Project. 1998. http://www.nh.ultranet.com/~shodkin/computer_recycling.htm

The Super User Group (a list of computer personnel at Yale University). Yale University. New Haven, Connecticut. Email survey interview.

University of Massachusetts. 1998. UMass Electronic Recycling Grant Proposal. February, 1998.

Used Computer Equipment Recycling. 1998. http://www.cs.cmu.edu/afs/cs/usr/sdx/www/used-computer-equip.html

Yale Recycling Department. 1998. Waste Reduction Fact Sheet. Yale University. New Haven, Connecticut.

APPENDIX I Questionnaire for the Survey on Computer Recycling at Yale

(Please use additional sheets if necessary).

TO: Libraries
Information Directors of Departments in Schools and Colleges

1. Do you know Yale has a Computer Recycling Program that helped recycle 6.3 tons of computer hardware last year?

☐ Yes ☐ No

a. If Yes, how many computers has your department channeled through them? ________

b. What else do you do with your old computer hardware? (please provide numerical estimates)

☐ Closet-fill ________ ☐ Retrofit (i.e. email Kiosk) ________

☐ Donate ________ ☐ Others ________

2. How many computers are currently in use in your department? (give an estimate)

3. Do you expect this number to increase in the future?

☐ Yes ☐ No

4. What is the average turn-over for computers/How long are they used?

____

____

____

5. Do you buy your computers through Yale's Micro-Computer Support Center (MCSC) or directly from a distributor? If not, where do you buy them?

____

____

6. How many computers do you buy in a year? (If purchasing is through multiple routes, please indicate source; for instance: 10 monitors – 5 MCSC, 5 non-Yale).

☐ Monitors	_____	☐ CPUs	_____
☐ Laptops	_____	☐ Printers	_____
☐ Scanners	_____	☐ Other	_____

Bonus Question:

Would computer recyclability ever be a purchasing consideration in your department?

APPENDIX II Yale Computer Recycling Project

DRAFT STATEMENT OF WORK
as of 4/20/1998

1. Task Order Title: Computer Recycling Pilot Project

2. Background: As part of an Industrial Ecology course project at the Yale School of Forestry & Environmental Studies, we are investigating the computer recycling market in the New Haven Area. In particular, we wish to determine whether it is economically feasible to continue and expand the current computer recycling program at Yale. At present, the Yale Computer Recycling Program collects approximately 300 computers (CPU and monitor) per year. Based on a recent computer recycling survey conducted at Yale, we estimate that we may double to number of computers channeled through the program within the next year. This is based on the fact that many respondents were unaware of the existence of a Yale computer recycling program and a significant number of them expressed willingness to participate in the program in the future. Consequently, we plan to achieve a significant increase in computer recycling via increased publicity and more accurate computer outflow record keeping. Therefore, we wish to examine the possibility of establishing a Computer Resale and Recycling Pilot Project with Absolute Recycling and assess the economic value of implementing such a project.

3. Objectives and Length of Pilot Program: We wish to obtain a cost estimate from Absolute Recycling, Inc. regarding recycling and disposal services for computers that enter Yale's recycling program over a 12-month period. These services could include any of the following activities: refurbishment, resale, recycling, and smelting activities. The cost estimates should include all labor, supervision, equipment, vehicles, premises, license fees, and costs necessary to perform the service.

4. Scope: In order to assess a value on the program, we are providing a list of commodities that would be channeled through the computer recycling pilot project. Given the decentralized process of computer purchase and disposal within Yale University, it is extremely difficult to determine such a number; therefore, the numbers listed below represent our best estimates for a twelve month period.

Component	Estimated numbers
Monitors	300
CPU Model	
286	200
386	100
486	50
Keyboards	50

5. Specific Tasks: Below is a list of the tasks associated with establishing the subject project with Absolute Recycling, Inc. This is not a comprehensive list, rather it is a preliminary task list that should be viewed as a tool to help factor all costs associated with implementation of the pilot project.

TASK 1. STORAGE AND TRANSPORTATION:
Absolute Recycling, Inc. will provide trailers for placement of the computer equipment collected by Yale. Yale will contact Absolute each time trailers are nearing capacity. Based on current program figures, these calls will occur on average every three weeks.

TASK 2. COMPUTER COMPONENT VALUATION:
Upon receipt of the commodities, Absolute will inspect all units for the possibility of resale. Units with no value will be sent to the dismantle line, where they will be sorted into the proper material streams for recycling. Units that have possible resale value will be further inspected and tested for resale. Yale understands that upon further inspection, some additional units will be also be sent for dismantling.

TASK 3. TABULATION OF RESULTS AND DISBURSEMENT OF FUNDS:
Absolute will provide a monthly tabulation of results that includes number of monitors, CPUs, keyboards, and their corresponding weight figures. Based upon those figures Absolute will disburse the corresponding funds to Yale University.

6. Other Pertinent Information or Special Considerations:
Permits
Prior to the implementation of the subject project, Yale would require Absolute Recycling, Inc. to secure and maintain all licenses and/or permits as required by federal, state, or city government for the duration of the project. In addition, Absolute Recycling should be able to provide a Certificate of Destruction upon request, as well as proof that all materials are being sold or otherwise transferred by Absolute Recycling to a recycling facility.

APPENDIX III Computer Recycling Directory in New England (1998)

Recycling Firm	Address	State and Zip	Telephone
Absolute Recycling, Inc.	477 Elm Street, P.O. Box 26184, West Haven	CT 06516	203-932-2422
Absolute Computer Resource	155 Research Drive, Stanford	CT 06497	203-380-4600
Colt Refining, Inc.	12 Baer Circle, East Haven	CT 06512	203-466-2658
Computer Recycling and Refining	27 Ciro Road, Branford	CT 06471	203-488-1535
Handy & Harman	Precious Metal Refining Division, 300 Rye Street, South Windsor	CT 06074	203-289-4327
Boston Computer Exchange	210 South Street, Boston	MA 02111	617-542-4414 ext. 110
The Boston Computer Society	101 A First Street, Waltham	MA 02154	617-290-5700
Duseau Waste Industries	129 Elm Street, Hartford	MA 01038	413-586-4100
East-West Foundation Development Foundation	23 Dry Dock Avenue, Third Floor, Boston	MA 02110	617-261-6699
Educational Assistance Limited	Boston	MA	617-542-1234
E.L. Harvey & Sons, Inc.	P.O. Box 1243, Westboro	MA 01581	508-836-3000
Electronics Processing Association, Inc.	133 Congress Street, Lowell	MA 01852	508-970-2700
Electric Recyclers	Shewsbury	MA	508-842-3612
EPA	Foundry Industrial Park, 1A Foundry Street, Lowell	MA 01852	508-970-2700
Gordon & Co.	P.O. Box 893, Westborough	MA 01581	508-480-9370
IPL Environmental Products	Worcester	MA	416-931-6061
Molten Metal Technology	508 South Street, Holyoke	MA	617-487-7634
Monico Inc.	Lowell	MA 01040	413-522-3710
Omni CEO, Inc.	Cambridge	MA	508-937-5004
Polaroid Corporation	Bedford	MA	607-577-4106
Pre-Owned Electronics	21 First Street, Pittsfield	MA	800-247-5343
Recompute	337 Summer Street, Boston	MA 01201	413-496-9846
Rentax, Inc.	1A Foundry Street, Lowell	MA 02210	800-545-2313
RST Reclaiming Co., Inc.	61 Ward Hill Road, Haverhill	MA 01852	978-453-3425
SAR	207 Marston Street, Lawrence	MA 01835	508-374-0666
Tombarello Recycling, Inc.	Medford	MA 01841	508-682-5226
Tuft University	Office of Waste Management, Box 36710, Amherst	MA	617-627-3113
University of Massachusetts, Intermediate Processing Facility	15 Medford Street, Lawrence	MA 01003	413-545-4386
Windfield	1627 Straight Path, Wheatley Heights	MA 01841	508-689-2470
Alco Refiners	280 Water Street, Suite 5A, Newburgh	NY 11798	609-234-6156
Electronic Resource Recovery	P.O. Box 550, New Paltz	NY 12550	914-561-1900
Hudson Valley Material Exchange	29-11 Queens Plaza North, Second Floor, Long Island City	NY 12561	914-255-3749
INWRAP Materials Exchange Program	118 East 25th Street, Suite 10-A, New York	NY 11101	718-786-5300
Nacomex (National Computer Exchange)	130 East Merrick Road, Freeport	NY 10010	800-622-2239
Re-Used Goods	Hallstead	NY 11520	516-223-2522
Envirocycle, Inc.		PA	800-711-6010

APPENDIX IV Items Included in the Computer Scrap and Dismantling Category

I. ITEMS INCLUDED IN THE COMPUTER SCRAP AND DISMANTLING CATEGORY

1. Scrap Whole Computers: Scrap whole computers consist of whole, un-dismantled PC or mainframe computer systems.

2. Scrap CPU Units: Scrap CPU units consist of whole, un-dismantled CPUs (Central Processing Units), free of monitors or keyboards.

3. Populated Circuit Boards: Populated circuit boards consist of whole circuit boards will all components still attached (the term "populated" refers to the components "living on the board" i.e. ICs, Capacitors, etc).

4. Circuit Boards (sheared flush): Circuit boards (sheared flush) consist of unpopulated circuit boards or circuit boards that have had all the components removed either by manual dismantling (de-soldering) or by means of shearing the components off so that the surface of the circuit board is "sheared flush."

5. Soldered Circuit Board Trimmings: Soldered circuit board trimmings consist of trimmings or rejects from new etched (solder coated) copper clad circuit boards.

6. Finger Trimmings: Finger trimmings consist of gold-plated trimmed "male" cookout board connections trimmed in such a fashion as to remove any excess non-gold content materials, trimmed as close to the gold as possible.

7. Mixed Scrap Integrated Circuits (IC chips): Mixed scrap integrated circuits contain assorted integrated circuit chips, whole or sheared from populated circuit boards, free from other types of components. May include ceramic or balolite covered chips.

8. Sorted Integrated Circuits (IC chips): Sorted integrated circuits consist of a single sorted style of integrated circuit chip. Must be homogeneous material.

9. Scrap Capacitors: Scrap capacitors consist of whole or recovered capacitors. Must be primarily tantalum capacitor materials. May include sorted capacitors from populated circuit board shearing.

10. Mixed Components (sheared or dismantled): Mixed components consist of assorted electronic components recovered from dismantling or shearing populated circuit boards. Must be free of shredded circuit boards or trimmings of circuit boards.

11. Unclipped Internal Wires and Connectors: Unclipped internal wires and connectors consist of wires and connectors attached to wires from the interior of the computer. May include ribbon wire and fine plastic insulated wires (may not include double insulated wires).

12. Clipped Internal Wires: Clipped internal wires consist of wires from the interior of the computer. May include ribbon wire and fine plastic insulated wires (may not include double insulated wires). Must be free of all connectors.

13. Unclipped External Wires and Cables: Unclipped external wires and cables consist of wires and cables with connectors still attached. May include double insulated wires.

14. Clipped External Wires: Clipped external wires include all sorted trimmed computer wires and cables free of connectors and attachments. May include double insulated wires.

15. External Connectors: External connectors consist of sorted connectors, free of wires.

16. Transformers and Transformer Windings: Transformers and transformer windings consist of sorted copper wire coils on cores, free of attachments.

17. Scrap Drives: Scrap drives consist of assorted hard drive units or floppy drive units.

18. Scrap Keyboards: Scrap keyboards consist of sorted scrap keyboards.

19. Scrap Printers: Scrap printers consist of whole scrap printer units.

20. Scrap Plastic (computer shells): Scrap plastic consists of sorted clean plastic shells or outer cases of computers, video display units, keyboards, or printers. Must be free of metal (including screws) and other foreign materials.

21. Assorted Scrap Computer Plastics: Assorted scrap computer plastics consist of any part of the computer system made of any grade of plastic, sorted and free of metal or other non-plastic materials.

22. Scrap Floppy Disks: Scrap floppy disks consist of assorted used or unuses 3.5' or 5.25' floppy diskettes.

23. Scrap CDs: Scrap CDs consist of assorted used or unused compact disks.

24. Scrap Monitors (VDT): Scrap monitors consist of whole Video Display Terminals which contain a Cathode Ray Tube in a shell or case.

25. Other Computer Scrap: Other computer scrap contains miscellaneous computer scrap materials not included in the listed grades.

II. USED COMPUTER ITEMS CATEGORY:

- Used Home Computer Systems
- Used Commercial Computer Systems
- Used Computer Parts
- Used Printers
- Used Printer Parts
- Used Monitors
- Used Keyboards
- Used Disk Drives
- Used Computer Software
- Used Computer Manuals
- Used Computer Furniture
- Other Used Computer Items

III. ITEMS INCLUDED IN THE CRT (CATHODE RAY TUBE) RECYCLING CATEGORY:

1. Whole VDT/TV Scrap: Whole VDT/TV scrap consists of whole, assembled computer monitors, video display terminals (VDT) and television sets suitable for dismantling (uncrushed/broken); suitable for CRT recovery.

2. CRT Scrap: CRT scrap consists of scrap, whole or broken Cathode Ray Tubes; may contain cores and windings but must be free from metal and plastic frames.

3. 1/8" Recovered CRT Glass (Andela #16): Recovered CRT glass consists of Cathode Ray Tube glass processed and sized to minus 1/8" inch. Must be free of cores, metal windings, and other foreign materials. This is equivalent to Andela #16.

4. 3/8" Recovered CRT Glass (Andela #17): Recovered CRT glass consists of Cathode Ray Tube glass processed and sized to minus 3/8" inch. Must be free of cores, metal windings, and other foreign materials. This is equivalent to Andela #17.

5. CRT Tailings: CRT Tailings consist of CRT processing rejects and may include screens, cores, coils, windings, and residual metal from gun remnants.

6. Other CRT Scrap: Other CRT scrap consists of other CRT scrap not included in the listed grades.

New Milford Farms and Organic Residue Recycling 1997

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ABSTRACT
Established in 1990, the New Milford Farms (NMF) composting facility serves as a low-cost means of disposal for various industrial residues from Nestle USA, a large international food company. The NMF facility takes in organic feedstocks ranging from spent coffee grounds and industrial wastewater sludge to leaves and brush from nearby residents, and combines them to create fertilizing compost useful for farms and gardens. Located in New Milford, Connecticut, the facility receives significant inputs from as far away as Fulton, New York and Freehold, New Jersey. The NMF business of industrial composting is growing within the larger framework of an emerging movement toward large-scale composting. A closer look at NMF reveals an array of the challenges, benefits, and potential areas for improvement in industrial composting. Environmental policy, markets for soil amendments, and the science of composting all form a critical backdrop for this rural Connecticut enterprise and hundreds like it in the U.S. and elsewhere.

NEW MILFORD FARMS

Operations

The primary incentive for Nestle to establish New Milford Farms (NMF) was the need for a cost-effective means to dispose of organic residues from its Food Ingredients Company (FIDCO), located across the river from the NMF site in New Milford. FIDCO also was searching for an economical way to dispose of a steady stream of wastewater sludge containing hydrolyzed vegetable protein waste (8% solids). Previously, FIDCO disposed of its residues in an onsite landfill at relatively nominal cost. As that landfill approached capacity, management feared the prospect of transporting the waste to a more remote site at much higher cost. Thus, Nestle undertook the development of a waste management center in the form of New Milford Farms.

Unfortunately, the organic residues are not readily compostable since the physical properties lead to a nutrient-poor amendment with offensive odors. Specifically, the FIDCO residue contains significant salt content and, as Dr. Walter Carey, president of New Milford Farms noted, "Salt in, salt out!" (Carey 1997). The NMF staff has found that in order to create desirable compost, the FIDCO residues must be kept to less than 20% of the total production feedstock. Thus, they must find large quantities of "bulking agents" to mix with the FIDCO residues.

For much of its bulking agent supplies, NMF has turned to other Nestle USA facilities in the Northeast. The plant in Freehold, New Jersey is a giant manufacturer of instant coffee and tea, where spent coffee grounds and tea leaves were traditionally burned to generate steam, and the remaining ashes disposed of in landfills. In 1995, its main boiler needed to be replaced at an estimated cost of ten million dollars. Nestle USA, with the assistance of NMF, decided that instead of purchasing a new boiler, Freehold could send the coffee grounds and tea leaves, as well as wastewater treatment sludge (40% solids), to New Milford Farms. The relationship saved the corporation millions of dollars in capital expenditures and promised to save millions more in disposal costs.

New Milford Farms established a similar arrangement with a Nestle chocolate-making facility in Fulton, New York. NMF receives cocoa bean cleanings and, frequently, the clean cocoa bean shells themselves. From a Nestle research and development facility in New Milford, NMF receives small quantities of various foodstuffs ranging from pasta and bread dough to water chestnuts. All of these feedstocks assist NMF in creating compost while also greatly lowering disposal costs for Nestle. Waste products from these various corporate facilities are augmented by yard waste from local residents, including brush, Christmas trees, and pallets.

The supply of these inputs varies greatly with differing production schedules and by season. This variability, in combination with minimal on-site storage capability, makes managing inputs an extremely challenging task. For example, when the Freehold plant is running, New Milford will receive literally tons of spent coffee grounds and tea leaves. The plant combines the shipments with other materials on hand, including yard waste from nearby residents and cocoa beans from New York, to create compost. When the Freehold production run ends and the plant shuts down for a week, shipments from other sources continue to arrive at NMF, forcing compost production to continue, even though the "recipe" is radically different.

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An even more deleterious effect of the varied inputs is their tendency to create a compost of varying physical properties and quality, which is a challenge for sales and marketing efforts. NMF seeks greater consistency in its own end product in order to establish long-term contracts with consumers. More specifically, it would like to sell bulk compost to area farms, but the inconsistent nature of the product makes this difficult, since the farmers cannot rely on the product to provide the nutrients necessary for its specific crops and not to emit offensive odors. In short, the variation in properties and quality of the NMF compost make it almost non-marketable as a stand-alone product. The farm does have a large contract with Vermont Natural Agriculture, a maker of soil amendments and mulching products. However, Vermont Natural Agriculture utilizes NMF compost as an intermediate product, mixing it with either topsoil or cow manure to create a soil amendment for home gardeners.

In an effort to improve the consistency of its product, NMF is always on the lookout for alternative bulking agents to smooth the supply of inputs. Materials that have been considered include corrugated cardboard, waxed cardboard, pre-consumer restaurant and supermarket wastes, fly-ash from coal-fired utilities, and wastes from paper manufacturing. None of these has yet proved to be a perfect solution to the supply difficulties. Physical properties of supplies, difficulties stemming from waste haulers, or problems with permitting from the Connecticut Department of Environmental Protection (see section on Policy) continue to hinder the operation.

Benefits of Operation

At first, composting appears to be the perfect business opportunity: In what other business can one generate revenues for both inputs and outputs? Ideally, a composting facility collects payments for disposal of materials at the site, mixes up the residuals, lets them cure and then sells the compost to farmers and gardeners. Unfortunately, composting has not proven so simple or lucrative for New Milford Farms. The alchemy of transforming waste into money has been complicated by NMF's constraining relationship with Nestle.

At first, composting appears to be the perfect business opportunity: In what other business can one generate revenues for both inputs and outputs? Unfortunately, composting has not proven so simple or lucrative for New Milford Farms.

As currently operated and accounted for by Nestle, New Milford Farms posts significant losses (Ruhl 1997). However, common measures of financial performance do not capture the benefits that accrue to Nestle from NMF. For example, the annual financial statements for NMF do not include the disposal cost savings from the composting efforts. Dr. Carey has calculated that, after accounting for disposal costs savings, NMF does indeed turn a slight profit (Carey and Ruhl 1996).

Many other hard to measure benefits undoubtedly accrue to Nestle from operating New Milford Farms. For example, by not sending waste to landfills and other disposal facilities, Nestle lowers its risks of becoming involved in a Superfund site and generally reduces environmental liability. By going above and beyond compliance with environmental regulations, Nestle also enhances its relationships with state departments of environmental protection and the U.S. EPA, which may facilitate requests for new permits and encourage greater regulatory flexibility in the future. In addition, Nestle operations may benefit from improved public relations associated with a strong environmental reputation.

Currently, Dr. Carey must justify the benefits of operating NMF, since they are not readily apparent on paper. Hopefully in the future, firms will recognize both the tangible and intangible benefits of utilizing process residues and will make some effort to account for those benefits.

ORGANICS RECYCLING – A BRIEF HISTORY

Although large-scale composting NMF-style is referred to above as "an emerging movement," the idea of recycling organic residues has actually been around for a long time. Since antiquity, manure has been spread on fields. Yet in North America, early European settlers felt that fertile soil was unlimited and did not take the same care to replenish it as farmers had done in Europe. By the early 1800s, soil fertility was decreasing, and in searching for improvement, American farmers developed many of the ideas to which we are now returning.

In 1859 the New York State Agricultural Society encouraged farmers to follow the "universal law of compensation," wasting nothing by returning all of the organic and inorganic matter used by crops to the soil. In seeking a way to do this, New York City and Long Island developed a symbiotic relationship whereby agricultural products were delivered to the city from the island and, in return, residues from street cleaning (mostly manure from cart-horses), manure from stables and dairy processors, bone meal and dried blood from slaughter houses, ash from soap factories, and night soil were shipped back to the farmers. (Night soil was the euphemism for human sewage, processed into a fertilizer called "poudrette" by a French technique of composting with peat moss.)

In 1842, a contributor to the *American Agriculturalist* calculated that "manure" from the 350,000 residents of greater New York contained enough nutrients to produce four million bushels of wheat, and another city entrepreneur figured that New York urine could be worth $350,000 annually. Another estimate stated that by not using its night soil, the U.S. was losing $50 million annually, a figure nearly equal to the entire federal budget at that time (Wines 1985).

As the search for better fertilizers and the pressures for increased yields intensified, agriculturalists developed synthetic fertilizers that were easier to handle. This led to the booming fertilizer industry and commercial agriculture so familiar to us today. Somewhere along the way the cyclical nature of the "universal law of compensation" was forgotten. Anthropogenic nitrogen fixation (by fertilizer production and the planting of leguminous crops) is currently equal to naturally occurring nitrogen fixation; similarly, human induced nitrogen run-off is equal in magnitude to natural levels (Ayres *et al.* 1994). It takes eleven barrels of oil to make one ton of nitrogen fertilizer, so this is an energy intensive process (Beers and Getz 1992).

Meanwhile, our waste stream includes large amounts of organic residues that are either burned or landfilled. Municipal solid waste (including paper) is 60-70% organic (Harrison and Richard 1992). Livestock manure, if not properly reused, leads to leaching of nitrogen compounds (nitrates and ammonium ions) into drinking water and lakes, rivers, and oceans. It also emits gaseous ammonia and methane. Nitrates are both harmful to humans and damaging to ecosystems because they encourage eutrophication (proliferation of algae). Our current use of fertilizer and disposal of organic waste in landfills exemplifies a linear pattern of resource use. Growing evidence of its adverse impacts is prompting an ideological shift toward the kind of cyclical resource use suggested by the industrial ecology paradigm. Currently, operations such as New Milford Farms are returning to older concepts and attempting to bring our organic residues back into the cycle.

Our current use of fertilizer and disposal of organic waste in landfills exemplifies a linear pattern of resource use. Growing evidence of its adverse impacts is prompting an ideological shift toward the kind of cyclical resource use suggested by the industrial ecology paradigm. Currently, operations such as New Milford Farms are returning to older concepts and attempting to bring our organic residues back into the cycle.

Theoretically, all organic residues can be recycled into some further productive use, even if that use is nothing more than returning the elements contained in the residues back to the cycles of which they were part (Grogan 1997). Some residues, such as cardboard and paper wastes, can be returned directly to the same production processes. It is most efficient for them to be a source of fiber that is re-pulped and used for new paper or cardboard. Other residues, such as manure, sewer sludge, or wood chips, can be applied directly to land areas so that the carbon and nutrients in the residues are ultimately available for reuse by microorganisms and plants. A drawback here is that, as the residues are broken down by decay organisms, many of the nutrients represented by the residues are tied up for a period of time by microorganisms and are not available to support the growth of preferred crops. The way around this drawback and the way to turn virtually all residues into desirable forms for reuse is to compost them.

The composting process breaks down the more complex structures within the organic residues, reducing the material to fundamental components that are useful as inputs to subsequent organic processes. The composter must mix inputs carefully to achieve the proper moisture content, carbon to nitrogen ratio, porosity, and dilution of less desirable elements (e.g. salt and oil). As composting is essentially "human guidance of decomposition by bacteria" (Harrison and Richard 1992), everything must be done to provide an optimal environment for the microscopic workers. Plenty of oxygen must be provided. Temperature must be regulated so as to be high enough to kill pathogens and low enough not to kill important bacteria or to create odors.

Yet, within the constraints of the process, different residues can be used as inputs in order to produce composts best suited to the desired use. Animal manures, as an example, are high in nitrogen after composting, but relatively low in carbon. They are best suited for use as a fertilizer that is applied to existing growing media. Combining the manure with yard wastes, sawdust or other materials high in carbon produces a compost that is more balanced in its final carbon to nitrogen ratio and therefore better suited to standing alone as a growing medium. Some of the resulting nutrients in compost are in a form immediately available to plants, and some require further breakdown time to be ready. This means that compost is essentially a slow release fertilizer, which reduces the quantity of excess nutrient run-off.

In addition to providing nutrients, composted organic residues have other benefits for agriculture. Compost can retain more water than the inorganic components of soil; therefore, if it is spread over fields as a mulch it reduces the amount of water required for irrigation (Grobe 1994). By retaining water it also slows leaching of nutrients and contaminants such as heavy metals and pesticides from the soil. The organic molecules in compost also directly bind to heavy metals and nutrients, thus holding them in place (Harrison and Richard 1992). This quality has led to the suggestion that compost be used as a filter for city stormwater to absorb grease, oil, heavy metals, and insoluble chemicals (Rogalski and Charlton 1996).

Another beneficial quality of compost is that the bacteria that are part of the composting process produce fungicides as a means of competing with the fungi that also live off of the compost. Repeated trials have led to evidence that the

Another beneficial quality of compost is that the bacteria that are part of the composting process produce fungicides as a means of competing with the fungi that also live off of the compost. Repeated trials have led to evidence that the fungicides present in compost are beneficial to plants that might otherwise suffer from fungal infection (Harrison and Richard 1992).

fungicides present in compost are beneficial to plants that might otherwise suffer from fungal infection (Harrison and Richard 1992). Processors are further developing ways to innoculate compost mixes so as to increase what is already a naturally derived capacity for suppressing disease through the action of desirable microbes (Segall 1995). This replaces the need to use what have been large amounts of fungicides to prevent the establishment and spread of several damaging diseases.

Composting can take place in backyards, in household worm bins (where worms rather than bacteria decompose the organic scraps), and in large facilities. Large facilities can use piles, or windrows, or in-vessel composters. New Milford uses a combination of the latter two. Mechanized turning speeds up the process and reduces odors by providing aeration. In-vessel composting units allow for some anaerobic composting, from which methane can be harvested as a power source.

Large-scale composting requires some safeguards. It is important that large composting facilities have a means of collecting the odorous gases generated, and that they be designed to prevent runoff of liquid from the compost. They also must take care to protect their workers from exposure to pathogens and allergens that may be present during the composting process. Initial heat-generating composting can take from a week to a month, depending on the techniques used, whereas curing (the slower process that brings the compost to maturity) requires from one to six months (Harrison and Richard 1992). Large scale composting facilities must be carefully designed to take all of this into account, and there is a fast growing industry of compost machinery manufacturers and compost research labs to facilitate design and implementation.

An interesting question arises here: if all possible organic residues were harnessed for composting, would that generate enough organic fertilizer to replace commercial fertilizers? Just looking at nitrogen, Figure 1 proposes a technique for answering this question. Beginning with "plants" in the upper right corner, if we know the total mass of plants harvested for human and livestock consumption per year and the average nitrogen content of these plants, we can assume that this is the amount of nitrogen entering the human realm. Unlike carbon, which is used up for energy and released to the atmosphere as carbon dioxide, nitrogen tends to remain behind, i.e. the amount of plant-derived nitrogen consumed by an animal will either become part of that animal or be excreted as urine or manure. Any nitrogen that does not go into yearly growth of livestock and humans will be passed on into the compost stream along with plant residues from agriculture, food processing, and institutions or households.

The wood and paper industry and the fiber industry also have organic inputs and outputs. These tend to have lower nitrogen content, as it is the green parts of the plants that have higher nitrogen content, but residues could still be composted. During the composting process, nitrogen is used by microorganisms for growth and carbon is used for energy. As mentioned above, this means

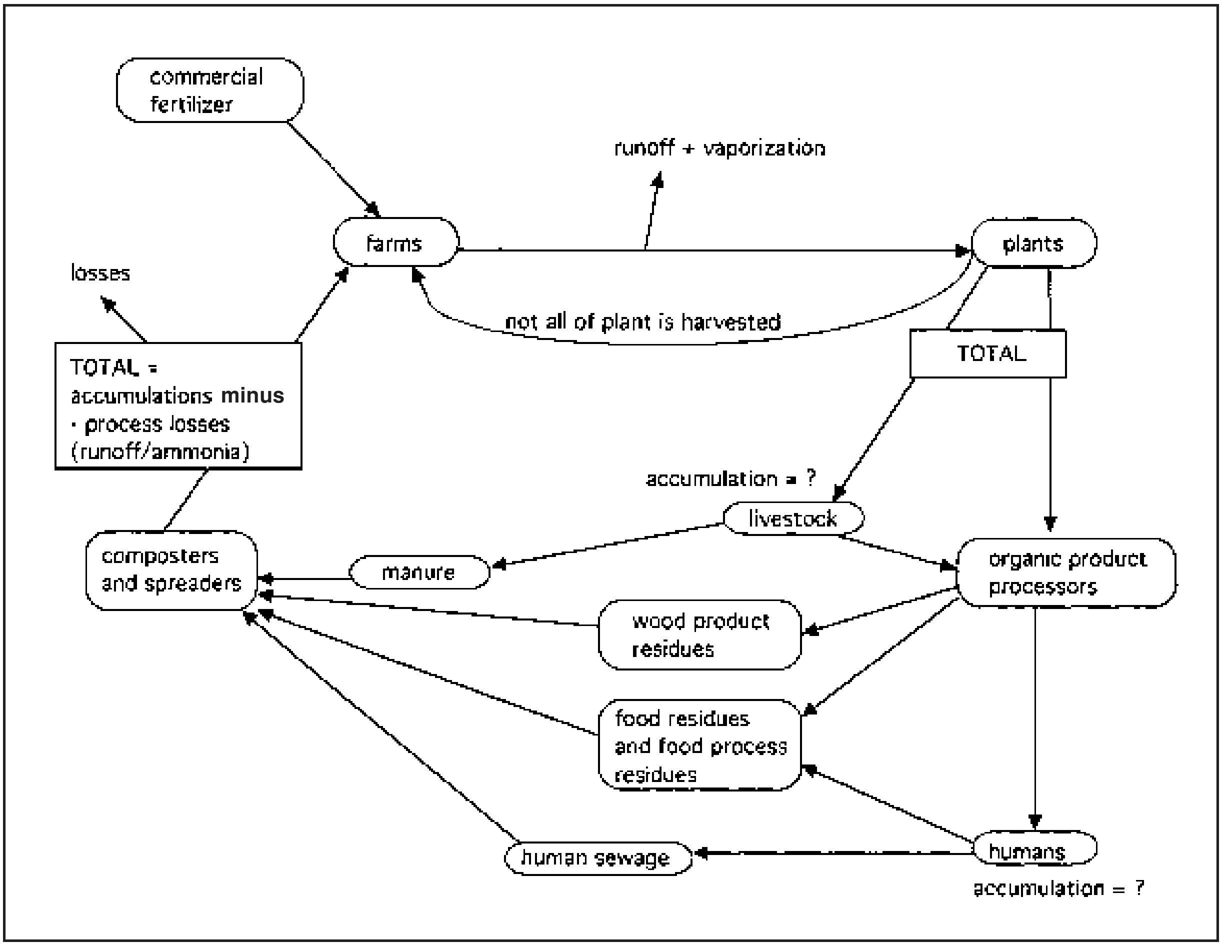

Figure 1 The Anthropogenic Nitrogen Cycle

that the carbon is released to the atmosphere, while the nitrogen remains present in the compost within the microbes (which break down over time). Some nitrogen is removed to the atmosphere by denitrifiying bacteria, but during the compost process the Carbon:Nitrogen (C:N) ratio tends to drop from 30:1 to 10:1, so the majority of the nitrogen remains (NRAES 1992).

In 1994, world use of nitrogenous fertilizers was 73.6 million metric tons. The form of nitrogen referred to in this figure was not specified. It probably was not elemental nitrogen, but rather nitrate or ammonia. So the total weight of elemental nitrogen used may well be substantially less than 73.6 million metric tons (if the figure refers to nitrates, then the weight of nitrogen alone is about 22 million metric tons, so we can estimate world nitrogen use to be 22-74 million metric tons). A rough estimate of world agricultural production for 1994 is 5 billion metric tons (FAO 1996). This is the sum of world production of primary crops and includes animal feed, and supposedly pasture as well. It may not include parts of the plant that are not harvested (such as cornstalks), but this plant matter is generally returned to the soil in current practice.

Assuming that the average dry nitrogen content of this organic matter is roughly 2% and that the average moisture content is 30% (because grains make up a large portion of this total and are relatively dry), this would mean that the amount of plant matter above would contain 60 million metric tons of nitrogen (NRAES 1992).

Certainly not all 60 million metric tons could be recycled because some would become part of people and some would become part of animals and some would be lost on the way to run-off and ammonia gas. By one estimation, 5-20% is assimilated and 23 million tons of ammonia are emitted by manure from domestic animals, though this amount might go down if more of the manure were composted. So perhaps 33 million metric tons of nitrogen could be cycled back through (60 million metric tons of nitrogen, minus 20% assimilation and an estimated 15 million metric tons lost to the atmosphere as ammonia). This is a very rough estimate, yet gives a sense of the magnitude – 33 million tons is a large fraction of the 73 million tons of fertilizers used. It certainly would require the incorporation of human and animal manure to achieve this result, since this amount of nitrogen cannot be sequestered from vegetable residues alone.

Currently in developed countries, fertilizer use is decreasing, as there is increased use of leguminous crop cycles to increase nitrogen content of the soil.

It also makes sense to look at countries individually, since it is unclear, in the long run, if residues generated in one country would be shipped to another for use. Some imbalances will arise in the case of countries that import much of their food or export much of their agricultural production. An important note is that while organics recycling could not entirely replace the use of synthetic fertilizers, the additional beneficial effects of compost (decreasing run-off, increasing plant absorption of nutrients) improve the outlook. We probably do not need all of that fertilizer since much of it ends up as run-off. Currently in developed countries, fertilizer use is decreasing, as there is increased use of leguminous crop cycles to increase nitrogen content of the soil. Certainly it is a worthwhile effort to capture as much organic material as we can for recycling.

ORGANICS RECYCLING – THE LOGISTICS

Closing the Loop on Organic Residues

Regardless of the type of residue, compost, or potential application, these various materials can find a place on the closed loop of organic recycling represented by Figure 2. Organic residues are generated by a wide range of private, commercial, and public activities. Currently if the residues cannot effectively be used at the site where they are created, they are likely to end up in landfills or incinerators. Although the theory and technology exists for effective composting, the logistics of actually gathering the material and setting up profitable composting facilities are still tricky (as New Milford Farms has found). Compost processors can choose how they want to work – with a limited number of residue inputs generating an output useful for specific types of applications, or with a wider variety of inputs to create outputs that have a broader array of possible applications. What the processors turn out as product is influenced by opportunities to find a demand among a variety of customers for alternative types of compost. These customers, in turn, are often generators of residues that feed additional composting activity.

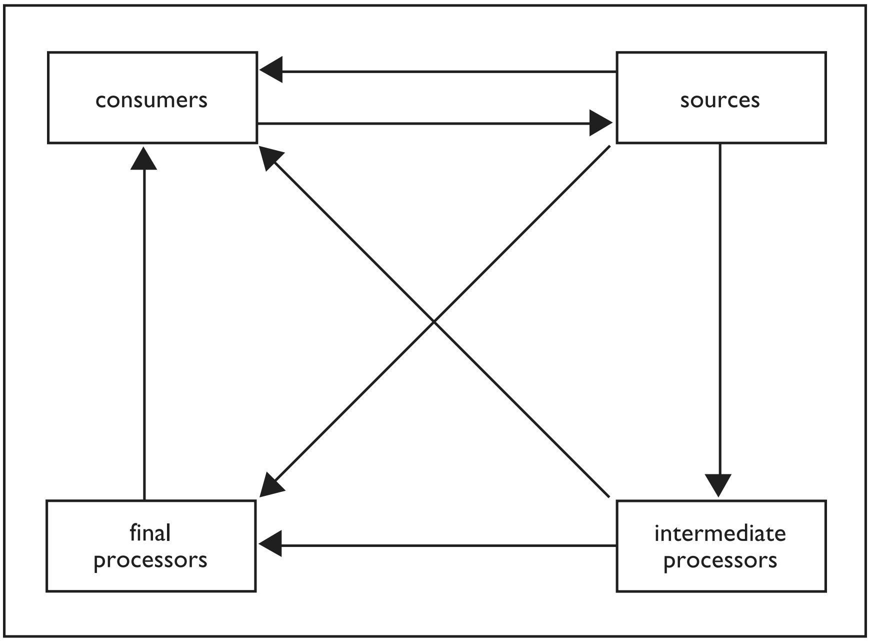

Figure 2 Closing the Loop on Organics

Demand for Compost

In considering the components of this loop more closely, we find that the consumers are the ones driving much of the activity. As opportunities and limitations associated with the use of compost are understood by more and more people, interest and demand continues to grow. Concerns about pathogens threatening humans are addressed by practices that properly subject compost to temperatures high enough to kill all pathogens. Increased awareness of what plants need for good growth, as well as what goes into developing a soil that supports maximum growth, leads to a better appreciation of the benefits of compost.

Home gardeners are attracted to compost as a potting mix, a medium for raised beds, or an amendment for garden soils. In the first two instances, a compost made from a blend of inputs can produce a finished product that is, by itself, sufficient as a planting medium. For soil amendments, manure or sludge-based composts can be good nutrient sources, while yard waste, leaves, or woody residues make compost good for soil conditioning. Professional landscapers and municipal groundskeepers are increasingly finding compost sufficient to fulfill these needs.

Commercial nurseries and greenhouses can meet almost all of their planting media needs with carefully blended composts. Given the highly mechanized and automated systems used commercially to fill containers and apply water and nutrients, it is essential that the compost be uniform and consistent. This is certainly possible, but does require that the compost processor exercise tight constraints regarding inputs and composting methods.

Farmers are under increasing pressures and regulatory requirements to control the use of nutrients on the farm. Farmers need to test soil carefully to determine kinds and amounts of nutrients needed to grow a particular crop (Bellows 1997). If they spread manure from their own operation, they are required to test the manure to determine the level of nutrients it represents. In the past, manures and crop residues or cover crops have been incorporated into the soil to help improve the soil structure and water handling characteristics. Organic farmers, but increasingly all farmers, are looking at appropriate composts as sources of most of the nutrient requirements for their crops. Not only can the compost supply all of the necessary nutrients, but they become available to the crop gradually rather than all at once. This is more coordinated with the requirements of the plants and reduces the potential that excess nutrients will be carried away by overland flow or groundwater. Compost from different types of inputs can work well for farmers, as long as the nutrient content is known and factored into the site and crop requirements. Widespread use of compost by farmers has the potential to increase demand dramatically over what it has been.

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An important requirement if this potential demand is to actually develop is that adequate amounts and types of compost be available for farmers at reasonably competitive prices (Humphries 1997). While nutrient needs may be met presently by having inorganic fertilizer spread by a commercial applicator for a total cost of approximately $20 per acre, fulfilling those same nutrient requirements with manure costs closer to $50 per acre (Humphries 1997). Inorganic fertilizers can be made more expensive through input taxes, but it may take some type of cost incentive on the other end of the scale to shift the emphasis to organic sources of nutrients (Runge 1996).

Sources of Organic Residues

Increased demand for a variety of composts would create economically attractive opportunities for recycling many organic residues. Large volume generators such as sewage treatment plants, larger confined animal feeding facilities, industrial operations, and forestry or wood products operations have been coming under increased pressure and costs to dispose of organic waste streams in ways that do not add to the landfill burdens or incineration loads. Moving these materials to composters already can be a lower cost option. The major constraint is often the cost of transporting bulky, often liquid, material over any distance that exceeds five to ten miles.

The prospect of increased demand brings with it the prospect of many more processors finding opportunities to start operations closer to larger sources and larger customers. More facilities operating throughout a region decreases the cost of moving residues from generator to processor. Private haulers who find it expensive to keep material separated while transporting it over longer distances are able to offer the service at more reasonable prices over the short haul. This in combination with lower tipping fees for recyclables, compared to general trash, makes separating organics more attractive for most generators. This is especially important for food wastes (created at institutions, restaurants, stores, and even homes) that have not been economically feasible to work into the compost process, primarily due to transportation costs (Pizzimenti 1997). There has also been experimentation with composting of mixed municipal wastes, where the facility separates the organic materials from the waste stream, but this can lead to high levels of heavy-metal contamination. Research shows that source-separated collection is much safer and more effective (Harrison and Richard 1992).

While it may be possible for private, commercial, retail, or public facilities to separate and ship their organic residues to compost facilities, some may choose not to send it away. Homeowners may find it desirable and cost effective to compost material in the back yard and use it around the house or garden. Some institutions such as prisons and schools have set up compost operations on site to handle food wastes and other organics. In such cases, the compost is usually used on site. Farmers generating large amounts of manure or crop residues have experimented with composting on site, then reusing the material on the farm or selling it. They may look to supplement their inputs by taking in domestic or municipally collected yard wastes and leaves. Few of these have developed into profitable additions to the farm operation (Ruhf 1997) so it is likely that as separate commercial facilities become available nearby, these farm-based operations will shut down and the waste will be shipped to the local processor.

Increasing and varied demand for compost from farmers, commercial growers, and others will combine with increased desire from generators to find cost effective disposal options to make it possible for processors to set up numerous facilities, broadly distributed and focused on matching local demands with local supplies.

Processors

The processors become the facilitators of moving organic residues from the generators to customers while transforming it into a useful material. Increasing and varied demand for compost from farmers, commercial growers, and others will combine with increased desire from generators to find cost effective disposal options to make it possible for processors to set up numerous facilities, broadly distributed and focused on matching local demands with local supplies. Often, these facilities will focus on processing large volumes of certain specific types of residues generated in an area to go to a small list of customers who have particular applications for the outputs produced. New Milford Farms is a current example of that type of operation.

Alternatively, the processor may focus on generating complete, finished compost for a more broad market of private and commercial growers. These processors will have to set up in locations where they not only can find suitable markets, but also where they can line up the appropriate inputs to create the product needed. Some processors may be involved in more than one type of production at the same time. Flexibility becomes an important component of responding to local demand and supply opportunities. Being able to move these materials within local areas is an important part of keeping costs down and increasing the likelihood that most organic residues will find their way into some type of recycling.

Hurdles to Realizing the Possibilities

Interest in recycling organics through composting has grown as concerns about landfills have increased (Sellew 1996a). Many regions were developing conceptual plans targeted to moving most organic waste into composting, but, simultaneously, many of these same areas were exploring and going forward with improved incineration technology as an alternative means of disposal (Jeffrey 1997). Municipalities have made commitments to regional incinerators that essentially preclude considering composting alternatives and even reduce the incentive to separate recyclables at the source (Sellew 1996b). Leaves and yard wastes have been an exception in that more and more municipalities and private composters (often farmers adding the material to manure) are finding it cost effective to compost this material for local use (Sellew 1996a).

Overall, the current state of regulations and disposal alternatives leaves composting lower on the list. Large regional landfills are operating at low enough costs with enough land area available to be the lowest cost disposal option for the foreseeable future. Collection and transport of unseparated wastes costs less than handling separate materials and adds to the attraction of landfilling (Sellew 1996b). Until space limitations or safety concerns raise the cost of landfilling significantly, it is likely to be the disposal option of choice for financially stressed municipalities and bottom line oriented businesses and institutions.

A LOOK AT COMPOSTING TODAY

Despite limitations, in the last ten years many new composting facilities have been initiated, putting us on the path toward realizing the possibilities described above. In California, the Good Humus Man (John Guzik) composts leaf cuttings from a lettuce packaging plant owned by Dole Corporation. The leaf cuttings used to be used as livestock feed, but now they are produced in such volume that Guzik saw the opportunity to cycle them right back onto Dole's fields rather than trucking them to livestock-producing areas. He mixes the lettuce with wood fines, cardboard, and manures. Dole has given him space and funding to develop his on-site composting facility, and the resulting compost is applied directly back to the farmland. Dole already has been using the water from cleaning the lettuce as irrigation water with some organic content (Grobe 1994).

Anheuser-Busch composts waste from a brewery in New York State, mixing sawdust as a bulking agent with cakes of high nitrogen content brewery sludge. In three years it processed 11,600 dry tons of sludge. The company markets its compost to All Gro, which is a mixer of soil products. The facility is similar in many ways to New Milford, except that it has simpler inputs and more control over them (Beers and Getz 1992).

The German company Herhof has 45 composting plants. One of them takes 21,000 tons per year of yard waste and household organics, another takes 27,000 tons. It stores excess summer woody material to be added as bulking agents in the winter when yard waste is less available. Its front loaders use biodiesel fuels and one facility gets all its power from methane gas from a nearby landfill. It uses a 7-10 day in-vessel process and then lets the compost mature outside for 12 weeks and makes 12 different product mixes, in addition to selling cheap carloads of unmatured compost to farmers.

Europe is on the forefront of the composting movement. In the Netherlands, household organic waste separation is mandatory. England has a profitable facility that collects household organics and sells the compost to gardeners. All together, home composting in England takes care of 2% of the country's total domestic waste, which comes to 400,000 tons diverted per year.

Spain has two mixed municipal waste compost facilities, one processing 108,000 tons and the other 87,000 tons. Glass, paperboard, plastics, and metal are also separated on site and sold for recycling. There are plans to use the compost for strawberry production (Rogalski and Charlton 1996).

Europe is on the forefront of the composting movement. In the Netherlands, household organic waste separation is mandatory. England has a profitable facility that collects household organics and sells the compost to gardeners.

An organic farm in Costa Rica uses a mixture called Bocachi, developed in Japan, as fertilizer. This is a combination of rice hulls, coffee bean shells, chicken manure, and cheese whey, and composts very quickly.

Canada composts 11% of its 6.2 million ton per year organic waste stream with 161 facilities, 50 of which are private and 111 municipally owned (Rogalski and Charlton 1996).

In 1995 in the United States, 500,000 tons of food scraps were composted out of 14.1 million possible. This means that 4,000 tons of nitrogen were recovered out of a possible 110,000 tons, which is still only 1% of U.S. nitrogenous fertilizer use, so the U.S. would have to compost materials beyond food scraps to make a big dent in fertilizer use. Some universities are beginning to compost their food wastes in addition to trimmings from grounds maintenance. Organic farmers use on-farm composting of seafood residues (high in nitrogen) as a source of fertilizer in Maine (Kunzler and Farrell 1996).

The government is beginning to take a role in promoting composting. The Iowa Department of Natural Resources Waste Management Assistance Division is developing a database of organic residues to improve on existing management procedures by aiding development of composting facilities (Hay 1997). This is along the lines of a vision for a public/private partnership in the building of composting facilities where the government would provide the land for the facility and take care of the permitting and collection procedures, and private companies would manage the actual composting and marketing.

This review of current composting practices shows that there is a lot happening, but it is not on the scale it could be, and certainly not enough for composting to approach closing the loop and reducing the demands for commercial fertilizers. Part of the hold up is the current regulatory climate.

Real concerns mixed with irrational fears combine to make us hesitant in this modern day and age to spread composted sewage sludge on fields. It is important to make sure that compost is safe and that the process is not a nuisance to nearby inhabitants. Regulatory variations from place to place lead to variations in the extent of composting. Europe has spent more time than the U.S. developing a regulatory environment that is conducive to composting. California, Texas, and Washington have drawn up regulations for specific source separated organics (Kunzler and Farrel 1996). This facilitates the initiation of new projects. It is important to consider how social policy influences the growth of the composting industry.

Social Policy Framework

The Resource Conservation and Recovery Act (RCRA) of 1976 is the federal statute that covers the handling of solid wastes, including garbage, sludges, and other discarded materials. Subtitle D of RCRA regulates solids not considered hazardous (the vast majority of solids, by far), including agricultural and manufacturing wastes of the kind we are considering here.

This review of current composting practices shows that there is a lot happening, but it is not on the scale it could be, and certainly not enough for composting to approach closing the loop and reducing the demands for commercial fertilizers.

Among the many issues surrounding RCRA's Title D is the question of pollution prevention and recycling. According to an Office of Technology Assessment (OTA) Background Paper (1992):

> RCRA's stated goal is to encourage the prevention of waste generation and the recycling or recovery of waste materials when possible. The Nation's experience with hazardous waste indicates that incentives to reduce waste generation and increase materials recovery have grown as the liabilities and direct costs of waste disposal and as right-to-know reporting...have increased. To date, however, EPA has not strongly promoted prevention and recycling of Subtitle D wastes, which may reflect the general lack of resources and lower priorities given over the years to Subtitle D compared to Subtitle C wastes. In addition, EPA is unable under RCRA to regulate production processes in terms of their later impacts on risks associated with the management of Subtitle D wastes...

The organic waste streams of interest to our group for this project – those from industry, municipal sewage treatment, post-consumer sources, and households – suffer from the regulatory neglect of Subtitle D wastes. The science of recycling organics creates opportunities that are captured by the spirit of RCRA, but neglected in practice. Opportunities are lost also because of state-by-state inconsistencies in the implementation of RCRA and state standards, as well as corporate disincentives to re-process organics. New Milford Farms operates in the state of Connecticut within 50 miles of both New York (upstate) and Massachusetts; NMF currently imports wastes from New York and New Jersey. And as noted above, Nestle USA operates NMF as a waste disposal alternative, not as a proactive organics recycler.

The same OTA background paper suggests the following as strategies for enhancing overall pollution prevention efforts:

- Increasing technical and financial assistance to businesses and states;
- Increasing the use of market-based incentives...to encourage innovative technologies and practices...;
- Removing existing regulatory disincentives to prevention and recycling; and
- Increasing public disclosure of emissions.

What is the regulatory environment for NMF in Connecticut? The Connecticut Department of Environmental Protection (DEP) permits NMF as a "volume-reduction" facility allowing up to 2,000 pounds of yard waste materials per day to be shredded or compressed in a process of composting. The State's dual purposes are to track the kinds and amounts of materials handled at the site, and to collect fees for same (Faryniarz 1997). While the Solid Waste Section of DEP handles the permitting process, the Bureaus of Water Management, Air Management, and Natural Resources must also ratify permits of the type held by NMF. Final permits are issued under site-related guidelines related to features of the site itself, access to utilities and transportation, and residential proximity.

The general framework of the permit allows certain specified substances to be handled, allows for demonstrations of expediency for new substances, and allows for flexible mixing ratios within parameters of safety (Faryniarz 1997). But Connecticut imposes some severe constraints, chief among them the requirement that all composting except leaf piles must be done indoors. Neighboring New York and Massachusetts do not require this.

Other legal forms of composting in Connecticut provide potential input streams for large-scale composting facilities like NMF which may turn out product ready-to-mix for active use. These include sewage sludge composting (which currently may not be used for anything other than landfill cover), manure composting, and clean wood chipping. At least one Connecticut official, Joe Faryniarz, sees a bright future for composting in Connecticut. An alternative to landfilling, composting also provides a vehicle for processing waste currently located in landfills as the latter are "mined" and revamped to hold the next generation of new opportunities to discover re-processing.

Connecticut also has a legislative mandate to produce a State Plan for solid waste management every two years. At this writing, the 1991 plan has not yet been replaced and it allows for recycling programs to include composting only if the material is actually re-used; objectives for composting on a large scale have not yet been addressed in a State Plan (Alexander 1997).

A major unmanaged stream of waste is from the commercial and institutional sector's organic fraction. It is not being separated at the source, but significantly, is being excluded from the tonnages required by towns to go to waste-burning power plants. DEP Compost Specialist K.C. Alexander sees a variety of possibilities for this stream: on-site composting supervised at first on a pilot basis by the state (projects are underway), expansion of existing sewage sludge treatment facilities to process food organics in separate bays, addition to farm-based manure composting, and entrepreneurial, source-separated facilities located along major state routes (Alexander 1997).

There is much to be done in Connecticut. Neighboring states (especially Massachusetts) are more actively promoting composting. A major educational effort must precede composting on a massive scale; the public would have to undertake this form of recycling with the same vigor now expended on collecting newspapers and cans. More difficult is the prospect of bringing the public around to accepting the usefulness of human sewage sludge in large-scale composting.

New Milford Farms and Industrial Ecology

We now can better place New Milford Farms into the context of the organics recycling movement and evaluate how it is doing and how it could improve. NMF successfully complements Nestle USA operations by converting significant waste quantities into useful, environmentally friendly end-products. New Milford Farms' mission is simultaneously its greatest strength and greatest weakness: as a subsidiary of a much larger corporation, NMF operates to serve the larger divisions which are its "customers." Its success is not measured based on efficiency of converting the most industrial waste into a useful end-product, or even on profitability. Thus, management cannot operate like an independent composting facility, limiting flexibility and total capability. For example, the farm is required to use waste residues from the FIDCO facility even though they lead to significantly worse compost. In addition, the production schedules of other divisions (made without regard to the needs of NMF) lead to compost of varying grades and physical characteristics, which is also not ideal for running an efficient composting facility.

NMF demonstrates the potential of regarding industrial waste as feedstock for alternative operations. The facility also illustrates how a large manufacturer developed a creative, environmentally-friendly solution to waste disposal issues. On the other hand, New Milford Farms also has its shortcomings. Using the matrix tool from stream-lined life cycle assessment, New Milford Farms received a score of 86 points out of a possible 100 (Graedel *et al.* 1995). The following table highlights the strengths and weaknesses of the facility.

As shown in Table 1, New Milford Farms achieves high marks – after all, it converts waste that otherwise would be landfilled or incinerated into a rich, environmentally friendly compost. Not surprisingly, the facility scores high marks for product use and refurbishment, recycling, and disposal. One interesting source of strength is gaseous residues during product manufacture – gaseous residues are normally high during composting. NMF reduced emissions by channeling the vapors underground, providing heat and nutrients to its lawn and flower garden.

Table 1 New Milford Farms Product Matrix

Life Stage	Materials Choice	Energy Use	Solid Residues	Liquid Residues	Gaseous Residues	TOTAL
Pre-Manufacture	3	3	3	3	3	15/20
Product Manufacture	3	2	4	4	4	17/20
Product Delivery	3	2	4	4	3	16/20
Product Use	4	3	4	4	3	18/20
Refurbishment, Recycling, Disposal	4	4	4	4	4	20/20
TOTAL	17/20	14/20	19/20	19/20	17/20	86/100

Note: Areas were rated on a scale of 1-4, with 1 being the lowest and 4 being the highest.

On the other hand, New Milford Farms suffers some low marks primarily because it lacks the autonomy to run its operations optimally. Energy usage during production is extremely high due to the long distances to its main suppliers. The coffee grounds, tea leaves, and wastewater sludge from New Jersey travel over 150 miles to New Milford, and the cocoa beans from New York travel over 250 miles. In 1995, NMF received over 60 truckloads from Fulton and nearly 700 truckloads from Freehold. Assuming that trucks travel at ten miles per gallon, transport of those inputs alone consumed nearly 24,000 gallons of fuel. New Milford Farms can improve the performance by "double-loading," but the fact remains that transportation of materials is not minimized. Product delivery also saw a couple of lower marks, primarily because the compost must often undergo further processing before usage.

The low marks result largely from lack of autonomy and regulatory freedom. Thus, they could be remedied if the facility operated independently and established high, constant levels of local supply and demand.

There is also a role for regulation in the composting movement. We see a future for regulation of nitrogen levels with state and federal monitoring sites; such an approach allows for planning the recycling of organic material in tandem with the reduction of commercial fertilizer applications. We see potential for community-based consensus models to expand the flexibility of solid flows to composting facilities, mediated by computerized databases of information on inputs and outputs. We also see potential for niche industries to act as intermediate processors of local organics which are fed into larger, more remote final processors.

Our vision includes the prospect of federally funded, regional pilot projects to plan feasible organics recycling systems that meet nitrogen standards at strategically identified check points. States can play a substantial role in setting appropriate costs for industry, institutions, and municipalities which fail to meet more stringent nitrogen management goals. In short, we see a future for public as well as private entrepreneurship in the field of organics recycling.

REFERENCES

Alexander, K.C. 1997. Connecticut DEP. Personal communication.

Ayres, R.U., William Schlesinger, and Robert Socolow. 1994. Human Impacts on the Carbon and Nitrogen Cycles. In Socolow *et al., Industrial Ecology and Global Change.* NY: Cambridge University Press.

Beers, Allen R. and Thomas J. Getz. May 1992. Composting Biosolids Saves 3.3 Million in Landfill Costs. *Biocycle:* 42.

Bellows, Barbara. 1997. Cornell Cooperative Extension. Personal communication.

Carey, Walter W. 1997. Manager, New Milford Farms. Personal communication.

Carey, Walter W. and Allan Ruhl. March 22, 1996. 1995 Operations Recap/ New Milford Farms (Memorandum to Celeste Miller).

Faryniarz, Joseph. 1997. Connecticut DEP. Personal communication.

Food and Agriculture Organization (FAO)of the United Nations - FAOSTAT Agricultural Data. 1996 http://www.apps.fao.org/lim500/nph-wrap.pl

Graedel, T.E., B.R. Allenby, and P.R. Comrie. 1995. Matrix Approaches to Abridged Life Cycle Assessment. *Environmental Science & Technology*. Vol. 29, No. 3.

Grobe, Karin. 1994. Composter Links up with Food Processor. *Biocycle,* July 1994, p. 40.

Grogan, Peter. 1997. Zero waste: is ecotopia possible? *Biocycle* 36 (1): 86.

Harrison, Ellen Z., and Tom R. Richard. 1992. Cornell Municipal Solid Waste FactSheets. Cornell Waste Management Insititute: Ithaca. from: Cornell Composting Website, http://www.cals.cornell.edu/dept/compost/MSW.FactSheets

Hay, Teresa D. 1997. Food Wastes Database Development RFP. Posting to the bulletin board of The Composting Resource Page website.

Humphries, Bruce. 1997. Owner, Odyssey Farm South, Inc. Personal communication.

Jeffrey, Roy. 1997. Cooperative Extension Service, University of Connecticut. Personal communication.

Kunzler, Conni and Molly Farrell. 1996. Food Service Composting Update. *Biocycle,* May 1996, p. 48.

Northeast Regional Agricultural Engineering Service (NRAES). 1992. Characteristics of Raw Materials. In: *The On Farm Composting Handbook*. From: the Cornell Composting Website - Carbon to Nitrogen Ratio. http://www.cfe.cornell.edu/compost/calc/cn_ratio.html

Pizzimenti, John. 1997. Operations manager, Somers Sanitation Service. Personal communication.

Rogalski, W. and J. Charlton, eds. 1996. European Survey of Organic Waste Treatment. World Resource Foundation, from the world wide web.

Runge, C. Ford. 1996. Agriculture and environmental policy: new business or business as usual? In *Environmental Reform: The Next Generation Project.* Yale Center for Environmental Law and Policy. Working Paper No. 1.

Ruhf, Kathryn. 1997. Executive Director, New England Small Farm Institute. Personal communication.
Segall, Lori. 1995. Marketing compost as a pest control product. *Biocycle* 35 (5).
Sellew, Paul. 1996a. Composting infrastructure development in the United States. Unpublished.
Sellew, Paul. 1996b. Economics/benefits of solid waste management alternatives - incineration, recycling, landfilling and composting. Unpublished.
Office of Technology Assessment (OTA),U.S. Congress. 1992. Managing Industrial Solid Wastes from Manufacturing, Mining, Oil and Gas Production, and Utility Coal Combustion—Background Paper, OTA-BP-O-82.
Wines, Richard A. 1985. *Fertilizer in America – From Waste Recycling to Resource Exploitation.* Temple University Press: Philadelphia.

FURTHER INFORMATION

Bouwman, A.F. 1996. Agricultural Statistics and Environmental Issues. *FAO Quarterly Bulletin of Statistics.* v9, n1-2, pIV (15).
Ruhl, Allan. 1997. Chief Financial Officer, New Milford Farms. Personal communication.

The Power of Trash: Harnessing Electricity, Carbon Dioxide, and Heat from a Landfill's Methane Gas
1998

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ABSTRACT
In this paper we analyze the economic, environmental, social, and legal implications of a proposed scenario, as well as alternative scenarios, for using the methane from a landfill in Groton, Connecticut as a source of energy. In the first section, we describe the current and proposed fuel cell system configuration. Then we describe the agreements and the parties involved in developing the system. In the second part of the paper, we define and evaluate four scenarios by using matrices to score their various implications. We perform this analysis examining the scenarios throughout their life cycles. In the final section we discuss the relevance of the final scores of the matrices and make recommendations for future development at the Groton Landfill.

INTRODUCTION

Connecticut Light & Power (CL&P), a subsidiary of Northeast Utilities (NU), New England's largest energy company, installed a gas pretreatment unit (GPU) and a fuel cell system at the Groton landfill. Both pieces of equipment are fully operational; electricity, carbon dioxide (CO_2), and heat are being produced. In fact, the power currently generated is capable of supplying the energy needs for more than 100 homes (NU*et al.*). The current proposal, however, is to use the electricity, CO_2, and heat generated by the fuel cell to run a greenhouse for growing tomatoes. Potentially, this would allow for a closed-looped system where all sources of heat and other wastes are commercially recycled within the system.

Generating electricity from landfill gas does not qualify as "business as usual." It does, however, qualify as an innovative approach to turning an otherwise damaging greenhouse gas into a productive feedstock.

Northeast Utilities is in the business of supplying electricity. Its website explains that "electricity is produced in a generating plant, *usually* by burning fossil fuels – coal, oil or natural gas – or through nuclear fission or hydro power" [emphasis added] (NU 1998).

Generating electricity from landfill gas does not qualify as "business as usual." It does, however, qualify as an innovative approach to turning an otherwise damaging greenhouse gas into a productive feedstock. Connecticut Light & Power is dedicated to reducing the environmental impact of the electric utility industry. "CL&P supports the development of cost-effective renewable resources, [and] alternatives to nonrenewable fossil fuels, for generating power"(NU 1998). The production of electricity from the gas emitted from the landfill at Groton, Connecticut is just one example of this support for environmentally friendly energy sources.

Groton Fuel Cell System Configuration

Wells and a flare blower are used to collect the landfill gas (hereinafter LFG) from the closed and capped landfill. That portion of LFG that is collected and not burned in the flare is then compressed and fed into the Gas Pretreatment Unit (GPU) (See Figure 1). Through a series of absorbers and separators the GPU strips away moisture and volatile organic compounds (VOCs) such as sulfides and halogenated compounds. The gas coming out of the GPU consists of methane (CH_4), CO_2, and trace amounts of oxygen and nitrogen. At the Groton site, the gas leaving the GPU is 57.1% methane, 41.0% CO_2, 1.5% nitrogen and 0.4% oxygen (NU_2).

This cleaned-up version of the LFG is then converted into electricity, heat, water, and CO_2 by the fuel cell system. Specifically, a fuel processor converts the raw fuel (primarily methane - CH_4) to a hydrogen-rich gas. Then the power section or cell stack of the fuel cell system converts the chemical energy of the hydrogen-rich gas into electrical energy and water. Finally, a power conditioner transforms this electrical power from DC power to AC power (International Fuel Cells).

Presently, only the electricity produced from the LFG is being used. However, if NU's full proposal is realized, the greenhouse will not only use the electricity, but also the CO_2 and the heat produced from the LFG. All three flows – electricity, CO_2, and heat – will play an indispensable role in growing the tomatoes (Figure 2).

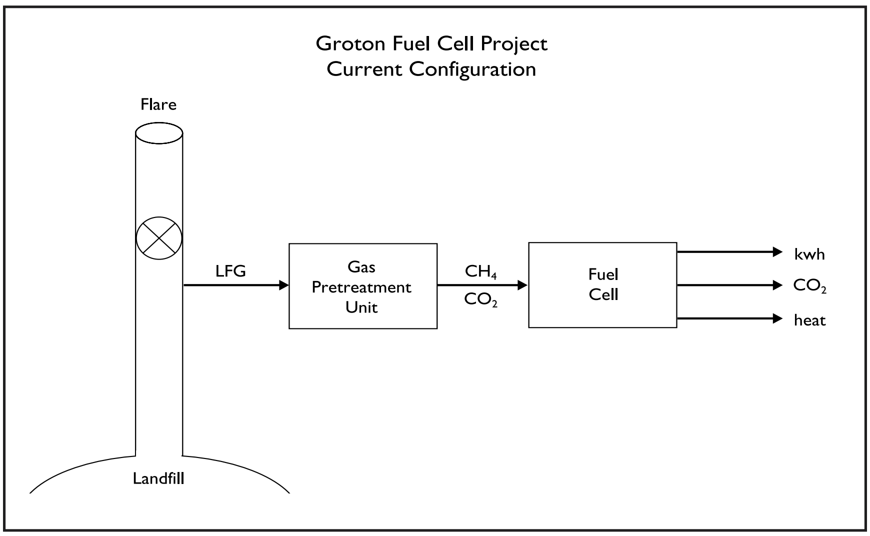

Figure 1 Groton Fuel Cell Project: Current Configuration

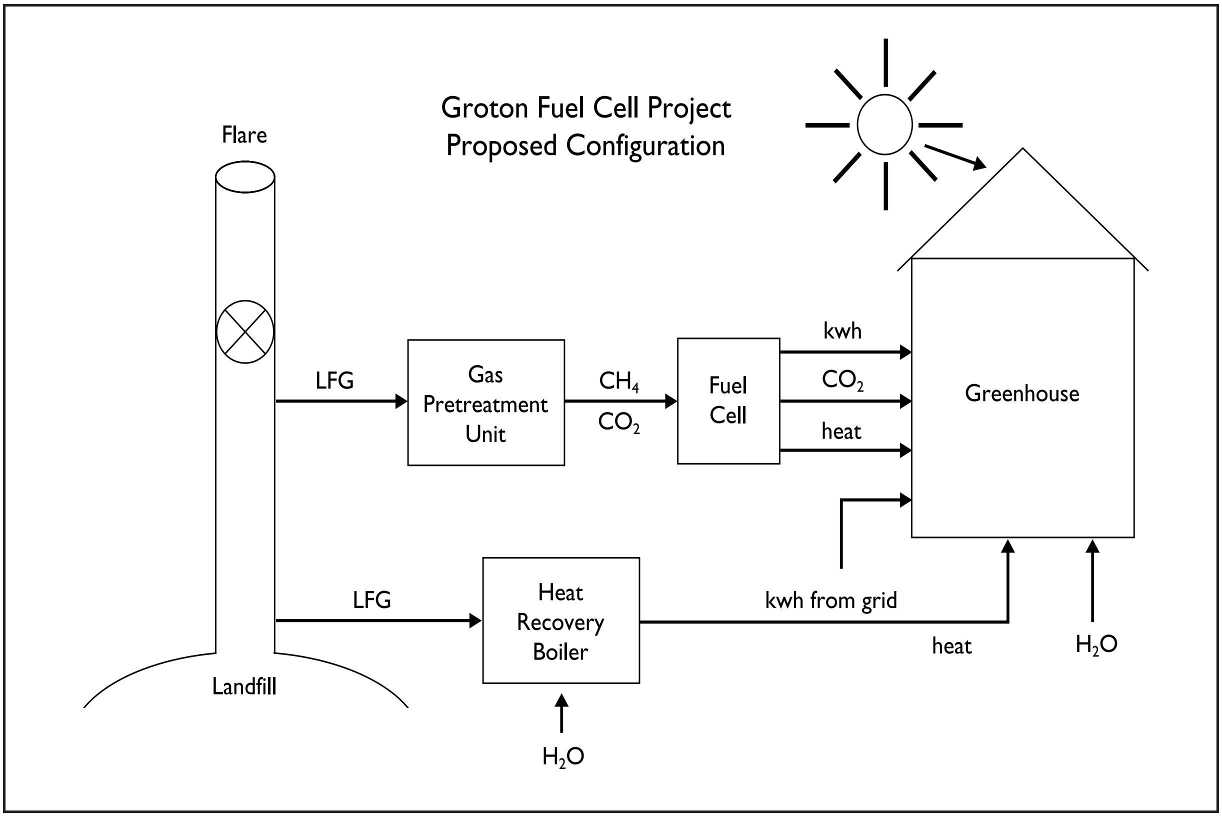

Figure 2 Groton Fuel Cell Project: Proposed Configuration

The Parties to the Project

Turning this proposal into a reality requires cooperation and commitment from a variety of participants: NU/CL&P, the town of Groton, a greenhouse owner/grower, an expert company in LFG projects, and the generating facility, known as "GENCO." A sixth party in the project is the entity known as "GASCO," which is responsible for the collection of LFG; the information provided to us about GASCO was unclear about the organization's exact role. GASCO and GENCO are both incorporated subsidiaries of NU/CL&P (GENCO may become co-owned by the LFG expert).

NU/CL&P is the nexus that connects all the other parties to the project. If the expert company does not become a co-owner of GENCO, NU/CL&P must recognize the importance and responsibility associated with assuming this central role. NU/CL&P remains the only party connecting all the other parties to this arrangement.

To truly grasp the different issues and concerns motivating each party in this project, one must first consider the status of each party. The town of Groton's operating funds come from the collection of taxes. It acts through elected representatives, who ostensibly are pursuing the best interests of their constituencies.

On the other hand, both the expert in LFG projects and the greenhouse owner/grower are private enterprises, with differing concerns regarding this project because the financial gains for each will come from different sources. The expert company will receive a fee from NU/CL&P. Alternatively, if the expert becomes a co-owner of GENCO, then some of its revenue will presumably come from the revenue collected by that company's sale of the LFG-derived electricity, CO_2, and heat. The greenhouse owner/grower, however, will obtain its revenue from parties not associated with this project, namely, supermarkets willing to sell the tomatoes or other crops raised in the greenhouse.

Falling somewhere in between the public/private distinction, NU/CL&P is a hybrid organization. "NU is an investor-owned utility relying on private-sector investments for operating capital. The shareholders of NU are individuals and institutions that hold shares in mutual funds, life insurance policies, pensions and employer 401(k) programs" (NU 1998). The public aspect of this party lies in the state's role in rate setting. "For the majority of electric customers in the country – including customers of the Connecticut Light & Power Company (CL&P) – rates are set by a state public utility commission. In Connecticut, the regulatory agency is called the Department of Public Utility Control (DPUC)" (NU 1998). By reviewing the agreements to date, several guidelines for the successful completion of this project – as well as its replication at other sites – have emerged. Each party will be considered separately.

First, the agreements between CL&P and the town of Groton make it clear that Groton should not represent an impediment to the continued pursuit and eventual completion of this project. In fact, the terms of the agreements between CL&P and Groton are so favorable to Groton that if similar terms were offered to other governmental entities in an effort to replicate this project elsewhere, it is unlikely that any other town or municipality owning a landfill would object (side note: The specific reasons for this conclusion are discussed in general terms because the agreements between the town and CL&P contain confidentiality provisions).

Groton appears to receive only benefits and no significant liabilities by participating in this project. In exchange for leasing the landfill property and providing CL&P with the gas emitted from the landfill, the town is given complete ownership of the condensate tank, its piping, and the electrical and foundation work needed to make the condensate tank operational. According to one town official, this equipment is estimated to be worth $200,000. Further, upon renewal of the initial 18-month lease, discussions will take place regarding the transfer of ownership of the permanent enclosed flare equipment. If Groton takes ownership of the enclosed flare, it will receive equipment valued at approximately $300,000. In all, the town might receive physical improvements totaling approximately $500,000 in exchange for allowing CL&P to use the methane coming from its closed and capped landfill.

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From the town's perspective, this is a good deal. The overall benefit for the town becomes even more evident when one realizes that by taking the LFG, CL&P is helping to relieve the town of an obligation it would otherwise have to perform. Because LFG is considered a greenhouse gas, environmental regulations would require the town to collect and then burn the gas if CL&P did not take it for use in its fuel cell system. By law, Groton is required to install an active gas collection system and a flare system. NU assumed responsibility for the insurance needed to protect the town from claims that may arise from this project. Finally, NU has agreed to favorably recognize the town in publications focused on this project. These combined benefits create an almost irresistible opportunity for Groton or any town offered the same terms.

For the private expert in LFG operations, the considerations are different. NU is considering the participation of an expert capable of bringing to the project detailed knowledge of operations and maintenance experience developed at the other LFG projects throughout the U.S., NU is also looking for this party to provide expertise regarding the current technology and research conducted on LFG clean-up systems. Additionally, the expert would be expected to work with the other parties involved in the project to expand the existing operations to include the greenhouse. Finally, the expert would be responsible for making sure all the tax advantages relating to this project are realized. In short, the expert would play a critically important role in the survival and success of this project. The generating facility includes all operations after the LFG recovery phase and before the electricity enters the greenhouse. By giving the expert a vested interest in the success of this project, NU would promote a high level of commitment throughout the entire life of the project. Therefore, we recommend that NU seriously consider making the expert a co-owner of the generating facility.

Accordingly, to make this project acceptable to any prospective grower, NU will have to guarantee a range of rates for the electricity, CO_2, and heat derived from the landfill gas regardless of the actual cost incurred by NU to produce those flows.

The third and final major party to this project is the greenhouse owner/grower. To date, no agreement which addresses the rights and obligations relating to this relationship has been adopted. Nevertheless, the status of any private grower brings to mind several considerations that NU needs to be sensitive to if this project is to be completed. As previously stated, unlike the other parties, the grower is dependent upon parties operating outside of this project. The grower's revenue will come from supermarkets willing to purchase and sell the fruits and/or vegetables the greenhouse produces. This situation subjects the grower to the vicissitudes of the fiercely competitive market for produce. This party will have to compete with other growers producing fruits and vegetables using conventional energy sources. Accordingly, to make this project acceptable to any prospective grower, NU will have to guarantee a range of rates for the electricity, CO_2, and heat derived from the LFG regardless of the actual cost incurred by NU to produce those flows. While the range of rates is subject to negotiation, undoubtedly NU will have to assume some risk to make this project enticing to a grower.

Similarly, the grower would need to be assured of a steady flow of these feedstocks. If the GPU or the fuel cell system breaks down, the grower would have to receive electricity, heat, and CO_2 from other sources. This potential obstacle is not insurmountable. Figure 2 shows that all the flows except CO_2 could enter the greenhouse from sources other than the fuel cell system. The CO_2 could be purchased from another source. (Whether CO_2 purchases from another source could be subsidized by NU is probably subject to negotiation.) Exhaustion of the LFG is estimated to take place in about 12-15 years. At that point, the grower needs access to another source of power to continue operating the greenhouse. If the grower were forced to cease operations after the LFG runs out, the project would be less appealing.

In summary, NU should recognize the potential difficulties involved in turning the proposed facility into a functioning reality. One area of potential difficulties is getting the cooperation and commitment from the parties participating in this project. For the reasons stated above, the town should not pose any problem. The expert, however, might not provide the level of dedication NU desires, unless the expert is given a vested interest in the entire life of the project. And finally, the grower appears to pose the most difficulties, primarily because the grower's revenue will come directly from parties operating outside of this project. The next section of this paper will compare NU's present proposal with several alternatives.

PROJECT EVALUATION

We conducted a qualitative assessment of four different scenarios for the use of the methane produced at the Groton Landfill:

Scenario I:
Methane gas from the landfill is used in the fuel cell system, which will then provide electricity, heat, and CO_2 for a greenhouse growing tomatoes. This comports with the industrial ecology concept of closing the loop.

Scenario II:
Instead of powering a fuel cell, the methane is used to power an internal combustion turbine to provide electricity for a greenhouse growing tomatoes.

Scenario III:
Similar to Scenario I, in that the methane gas from the landfill is used by a fuel cell to produce electricity. This electricity is fed into the established NU grid and excess CO_2 is vented into the atmosphere.

Scenario IV:
Similar to Scenario III, in that the methane gas from the landfill is used in a fuel cell system, which feeds electricity into the established NU grid; however, the CO_2 from the fuel cell is captured and sold.

Environmental, Social, and Economic Processes Evaluated

We will use matrices resembling those created by Graedel, Allenby, and Comrie in 1995 (Graedel *et al.* 1995) to analyze the principal environmental, economic, social, and legal implications throughout the life cycle of each scenario. We have divided the matrices into three life cycle stages: 1) development and realization, which includes planning, design, site selection, land surveying, and construction, 2) operation and maintenance, which includes the operation of the system once it has been built and actions taken to guarantee future operation of the system, and 3) disposal and reincarnation, which describes the final destination of materials including disposal, recycling, or reuse.

We will measure the environmental and social impacts by evaluating the following four issues: 1) natural resource use and land use, 2) waste generated, 3) economic factors, and 4) aggregate societal implications. These four issues will comprise the column headings of the matrices and are described in more detail below.

Specific Attributes

We have identified attributes within these four major categories that we feel are important to evaluate throughout the life cycle of the scenarios:

Natural Resource and Land Use

Land use
Natural resource use
Energy consumed

Waste Generated

Greenhouse gases (CO_2 and Methane)
Other emissions (transport, heat, combustion)
Solid debris
Waste water

Economic Factors

Fuel cell
Internal combustion engine
Greenhouse
Tomato revenue
Green electricity revenue
CO_2 revenue

Aggregate Societal Implications

Additional employment opportunities
Public image (green marketing, handicapped employment, closing the loop, partnering)
Legal encumbrances

Natural Resource and Land Use

Due to the nature of the four scenarios, we must assess the environmental impacts on the natural resources and land. We will pay attention to whether the scenarios include the use of pristine land ("greenfields") such as wetlands or forests, or land that has been developed previously ("brownfields"). We will attempt to measure the amount of natural resources that will be used for construction of infrastructure, operation, and demolition of infrastructure. We have also considered total energy consumed in each of the four scenarios, as this is directly related to natural resource use.

Waste Generated

Of principal concern is the amount of waste generated by the processes involved in the four scenarios. The amount of CO_2 and other greenhouse gases that might escape into the atmosphere is also a concern. In addition, we will attempt to measure the relative amounts of solid and liquid wastes that will result from construction and demolition of the infrastructure, as well as from the operational stages of the scenarios.

One of the principal focuses of this paper is to evaluate the use of industrial ecology concepts in the Groton Landfill pilot study. Thus the ability for partnerships to flourish between public and private entities to increase overall benefits will weigh heavily in our analyses.

Economic Factors

Using figures given to us by Northeast Utilities, we were able to conduct a quantitative economic cost-benefit analysis of the various scenarios to evaluate the commercial viability of each. The economic analyses are described in detail below.

Aggregate Societal Implications

In order to successfully measure both the economic factors and social values, we included pertinent social and legal attributes within our analyses. Among these attributes are such things as employment opportunities, public image or perception, repercussions of public and private partnerships, and the reliability of the energy sources. One of the principal focuses of this paper is to evaluate the use of industrial ecology concepts in the Groton Landfill pilot study. Thus, the ability for partnerships to flourish between public and private entities to increase overall benefits will weigh heavily in our analyses. In addition, we are interested in evaluating the scenarios for their ability to "close the loop," by minimizing the excess energy or heat lost from the system.

The evaluation of legal encumbrances takes stock of all possible legal impediments to the project. Specifically considered are the difficulties of establishing contracts and acquiring permits, possible legal liability occasioned by environmental laws such as Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or Resource Conservation and Recovety Act (RCRA), and general liability associated with the day-to-day operations of the enterprise. The principal hindrances stem from contractual and regulatory encumbrances such as building consensus among the parties, permitting, and compliance requirements. Additionally, general enterprise liability risks may be an identifiable source of legal liability. Risks such as worker's compensation and liability associated with negligent injuries increase proportionally with increases in activity. Finally, although it is a distinct possibility that some legal environmental risk may be encountered given the nature of the Groton landfill, little CERCLA/RCRA risk is likely to result directly from the scenarios considered.

Legal risks are unique in that they are largely private costs, and do not affect society in a significant way (except to possibly employ more attorneys than may be optimal). Accordingly, it is important to identify which parties are vulnerable to which risks. Although it is a slight simplification of the organizational structure, we will consider only three relevant principal parties: the town, the utility, and the vegetable grower.

The town's role remains unchanged across the scenarios. The town owns and maintains the landfill, and it would do so even if the fuel cell were not installed. It is then likely that it alone will bear most of the liability engendered by environmental laws such as CERCLA and RCRA. Liability risks associated with the landfill, although considerable, will likely remain separated from the other parties through the use of various legal instruments, although the other parties may feel the ramifications of such risk. If the town gets cited for violations, electricity generation may be stymied. But because our analysis concerns the incremental changes posed by the different scenarios, consideration of the town's underlying risk, i.e., RCRA/CERCLA risk, is largely outside the scope of our evaluation.

In contrast, the utility and the grower face the lion's share of the contractual costs and permitting risks. Transaction costs associated with making binding, legal agreements are considerable, and may rise to a level that thwarts further project development. Each party has different goals, skills, and bargaining strengths. Finding common ground is difficult, but of paramount importance to the viability of the project.

Also considerable are the regulatory hurdles. Although the work associated with securing permits is normally a very cumbersome task, the experimental nature of the project has presented some unique problems. The Connecticut Department of Environmental Protection is unsure of how to classify the clean water produced by the fuel cell. Such water is much cleaner than typical effluent flows, yet because it does not fall into any clear regulatory classification, the water can not be used for any useful purpose.

The Connecticut Department of Environmental Protection is unsure of how to classify the clean water produced by the fuel cell. Such water is much cleaner than typical effluent flows, yet because it does not fall into any clear regulatory classification, the water can not be used for any useful purpose.

Evaluation of Project Economics

Federal regulations already require many landfills to collect and burn their landfill gas emissions. This requires the installation of an expensive gas collection system. The operators of the landfill are then faced with two choices: 1) they can flare the gas, or 2) they can use the landfill gas for energy production. Both alternatives comply with environmental regulations but only the energy recovery option capitalizes on the energy value of landfill gas while displacing the use of fossil fuels. Once installation and operation of a gas collection system becomes a required cost of doing business, incurring the extra incremental cost of an energy recovery system becomes a more attractive investment. Sale and use of landfill gas will often lower the overall cost of compliance and may in fact lead to profit realization. The economics of a landfill gas-to-energy project, however, depend on a number of factors, including landfill gas quantity and quality, local energy prices, and capital costs of the equipment chosen. This section presents a methodology for evaluating project economics and compares the economic evaluations of the four proposed scenarios for Groton landfill.

Economic Evaluation Process

Like any economic analysis, an economic evaluation of a potential energy recovery project involves comparing expected revenues and expenses. For this purpose, the creation of a cash flow model is necessary. This model provides data for a relatively accurate estimation of the probable lifetime economic performance of a project, based on projected revenues and expenses. For an energy project, this in-depth economic analysis includes detailed calculations of project performance over time, escalation in project expenses and energy prices, financing costs, and tax considerations. Appendix A provides an example of a cash flow model for Scenario I at the Groton landfill, including the operation of a fuel cell and the construction of a greenhouse.

If the objective is to provide a cost-efficient pollution control measure, then financial concerns are not the only consideration and the acceptable rate of return might not be as high as in other commercial projects.

Based on the model, the project's feasibility is assessed by calculating annual net cash flows, net present value, and/or the rate of return. These measures of financial performance are calculated over the life of a project and are the most reliable measures of economic feasibility. The rate of return and the net present value of cash flows are two measures of the financial returns of the project. A preferred rate of return usually ranges from 12-18% for most types of power projects (U.S. EPA 1996). An acceptable rate of return, however, is a function of project objectives and risks. If the objective is to provide a cost-efficient pollution control measure, then financial concerns are not the only consideration and the acceptable rate of return might not be as high as in other commercial projects. Also, if risks are minimal because financing has been obtained from the government, permits are available, or extensive testing has been performed, lower rates of return may be acceptable.

When considering project development and implementation, it is often necessary to compare the proposed project to other alternatives. Cash flows of different projects can be compared on an annual, net present value, or rate of return basis. Economic performance, however, is not the sole basis on which a project is evaluated. Non-price factors, including environmental performance and social costs and benefits should also be assessed and incorporated into the analysis. The option that produces the best financial performance while meeting the desired environmental and social requirements is the overall winner.

Landfill gas power projects have the potential of improvement over time as most of the costs are fixed (e.g. capital and gas collection costs) and not subject to significant escalation over time. Project revenues can also increase over time as electric rates escalate and a market is created for renewable energy, thus offsetting increases in operations and maintenance (O&M) expenses. However, a major consideration in landfill gas-to-energy projects is the expected lifetime of landfill operation. A decline in the landfill gas quantity will diminish revenues in later years of the project operation. The expected lifetime of power projects using the gas from the Groton landfill is calculated at about 15 years. For other landfills, operations may be in the range of 20-25 years.

Economic Performance Assessment of Scenario I – Proposed Project

The economic analysis of the proposed project at Groton landfill, referred to throughout this paper as Scenario I, shows that this project does not show commercially acceptable rates of return (Note: The economic analysis in this paper is done using the confidential pro forma model supplied by Northeast Utilities and is based on the initial assumptions of the author of the model). The low rate of return on this project, 3.85% (See Appendix A), is due to the large capital investment required for the implementation of the project and the limited time and scope. There are only three acres available for the construction of a greenhouse and the lifetime of the project is 15 years. The capital costs for the fuel cell and greenhouse are $400,000 and $3,088,279 respectively.
These figures include excavation/backfill, sand, PVC sheeting, paved road and parking, and building costs on a three acre land parcel.

The expected lifetime of power projects using the gas from the Groton landfill is calculated at about 15 years. For other landfills, operations may be in the range of 20-25 years.

The evaluation of the economics of this scenario requires an integrated analysis of the cash flows expected by all the parties involved in the project – GENCO, GASCO, and the greenhouse.

The operating cash flows from GENCO and GASCO for the first year are projected at $68,354 and $111,722 respectively. The revenues of GENCO come from the sale of electricity, heat, and carbon dioxide to the greenhouse. Expenses include landfill gas fuel cost, natural gas, operation and maintenance expenses associated with the fuel cell, the capital cost of the fuel cell, as well as insurance, property taxes, and administrative expenses.

GASCO's revenues are primarily collected from the monetization of the Internal Revenue Service Section 29 tax credits. These tax credits are available under the "Renewable Energy Production Initiative" (REPI) program, which was mandated under the 1992 Energy Policy Act and is being implemented by the U.S. Department of Energy. The program provides an incentive to publicly owned facilities that generate electricity from renewable energy sources, such as landfill gas. Section 29 tax credits are due to expire in 2007. The credit is worth $5.83 per barrel oil-equivalent (on a MMBtu basis) and is adjusted annually for inflation. The current value of the credit is $1.001 per MMBtu and at full value, this converts to about 0.9c to 1.3c/kWh (U.S. EPA 1996). In the case of Groton, these tax credits are estimated at $111,722/year.

The operating cash flows of the greenhouse are estimated at $106,804. The revenues expected from the sale of tomatoes (average price $1.25/lb and an annual yield of 830,000 lbs) amount to $1,037,500 and are expected to increase by 2% annually. The operating expenses of the greenhouse (purchase of electricity, heat, CO_2, labor, insurance, administration, and property taxes) are expected to be $930,696 in the first year with a 2% escalation.

On the basis of these cash flows, the rate of return for the lifetime of the project, 15 years, is calculated. For Scenario I, the rate of return is 3.85%, i.e. about the same as inflation.

Therefore, the project will not be economically feasible as a commercial operation. However, a consideration of non-price factors is necessary in order for the analysis to be complete. A comprehensive evaluation of the project's feasibility and desirability will be presented later. The following section will discuss the economic feasibility of the alternative scenarios.

Scenario II: Jenbacher engine greenhouse

This alternative involves the operation of an internal combustion engine instead of the fuel cell at the Groton landfill site and the operation of a commercial greenhouse. This scenario exhibits a poor rate of return due to the large capital costs associated with the Jenbacher engine, ($1,676,000) and the large O&M costs. The engine's capacity is much larger than that of the fuel cell (988 kW as compared to 200 kW) but this leads to a lot of excessive production of heat which cannot be efficiently utilized. Moreover, the CO_2 produced as a result of the combustion is not as pure as the CO_2 produced by the fuel cell, which makes it a less valuable commercial product. The rate of return for this alternative is as low as 3.72%; on this basis, the project is not economically feasible.

The Restructuring Bill classifies energy into various categories and establishes requirements for the content of utilities' portfolios with the purpose of encouraging the use of renewables in energy production.

Scenario III : Fuel cell and sale of "green" power

This alternative suggests that the electricity produced by the fuel cell be marketed as renewable energy ("green" power) and supplied to the town of Groton directly, instead of building a greenhouse at the landfill site. In light of the new law on restructuring of the Connecticut electric industry, passed by both the House and Senate on April 15, 1998, it is conceivable that a market for renewable energy will emerge. The Restructuring Bill classifies energy into various categories and establishes requirements for the content of utilities' portfolios with the purpose of encouraging the use of renewables in energy production. The legislation mandates that license applicants must disclose their portfolio characteristics, such as fuel sources, emissions, and labor profile to consumers. To help customers compare products, applicants must supply standard disclosure labels that show the percentage they use of biomass, coal, hydro, municipal solid waste, natural gas, nuclear, oil, solar, wind and other renewables, such as fuel cells that use renewable fuel sources, landfill gas, and ocean thermal. The Bill defines Class I renewables as solar, wind, fuel cells, new biomass, and methane from landfills and Class II renewables as other renewables, including hydropower (Restructuring Bill 1998).

Section 25 of the Bill establishes a renewables portfolio standard for energy suppliers in the state. The requirement begins at 6% (0.5% for Class I and 5.5%

for Class II) and increases until 2009 up to 13% (6% for Class I) (Restructuring Bill 1998, Section 25a, p.59). There are limits as to the exent to which these requirements can be met with hydropower. Thus, the new legislation will require a large increase in renewables technology or purchases for Connecticut and it is likely to create a market for "green" power. The government's commitment to the creation of such a market and encouragement of a wider use of renewable energy sources is exemplified by the establishment of a Renewable Energy Investment Fund which will be administered by a quasi-public agency, Connecticut Innovations, Inc. (Restructuring Bill 1998, Section 44a, p.88).

The fund will use public money to leverage private capital for development of renewable projects. Money for the fund will come from a non-bypassable charge levied by distribution companies on all customers. The renewables research funding section requires all ratepayers to contribute a 0.05 cent/kWh charge starting in 2000, which would rise to 0.075 cent/kWh in 2002 and 0.10 cent/kWh in 2004 (Restructuring Bill 1998, Section 44b, p.88). Utilities will deposit the revenues in a trust managed by Connecticut Innovations, Inc., which will set up a plan to make renewables more affordable, educate the public about renewable energy, support growth through investment, and spur research and development.

Environmental regulations may thus increase demand for renewable energy and a market for "green" power is likely to emerge. The electricity from the Groton landfill is classified as Class I renewable energy and can be marketed as such.

Also under the bill, a retail user who installs certain renewable technologies at home can receive a credit for the energy produced. The local distribution utility must provide a metering system to determine the amount of energy produced on site and allow calculation of the credit. Further, the bill would allow municipalities to exempt renewable energy systems from local property taxes.

Environmental regulations may thus increase demand for renewable energy and a market for "green" power is likely to emerge. The electricity from the Groton landfill is classified as Class I renewable energy and can be marketed as such. For the purposes of the economic analysis of this scenario, it is assumed that the electricity generated by the fuel cell could be sold at 6 cents/kWh with an annual increase in price of 3%. The operating cash flows of GENCO in this scenario fall dramatically to a negative of $54,494. This is due to the fact that the other by-products, heat, and CO_2, are not sold since the greenhouse is not operating. GASCO retains the same cash flows as in other scenarios since its revenues come from tax credits monetization.

The cash flow for the whole project amounts to $57,228 annually with initial capital costs of $400,000 for the fuel cell. The rate of return for this scenario is therefore 4.21%, slightly above the inflation rate. This scenario, too, does not offer economic feasibility.

Scenario IV: Fuel cell, sale of "green" power and CO_2

Drawing on the environmental regulations argument presented for Scenario III, this scenario also envisions the sale of "green" energy. However, here we explore the option of selling one of the by-products from the generation of electricity by the fuel cell – carbon dioxide. The quality of the CO_2 produced by the fuel cell is very high and can allow the sale of commercial high purity CO_2. With retail prices for this product between $50 and $200 per ton (1992 figures), this may become a valuable source of revenue (U.S. EPA 1996).

The Groton landfill produces 12,060 tons of CO_2 (Reduction Investment Proposal for GENCO, draft 1997). For the economic analysis presented here, it is assumed that half of that amount is available for sale at $25/ton. In the absence of a greenhouse, the capital costs of the project drop dramatically to $500,000 (fuel cell capital cost of $400,000 plus estimated costs for equipment for bottling CO_2 of $100,000) and the rate of return increases accordingly to 42.14%. This rate of return ensures the profitability of the project even in the presence of relatively high risk and makes it an economically attractive alternative. The problems associated with this alternative, however, are that transportation of CO_2 is not economical if shipped outside of a 200-mile radius. This would require that enough end users of high purity commercial CO_2 exist within a certain range of the production location. Thus, depending on site-specific factors, this scenario may have different applicability to different landfills.

Economic Comparison of all Options

The economic analysis of the four scenarios shows that financial returns on a landfill gas-to-energy project are not expected to exceed a few percent in most cases. The following table presents the results of the analysis:

Table 1 Economic analysis of the four scenarios

Scenario	Rate of Return	Matrix Evaluation
Scenario I Fuel Cell and Greenhouse	3.85%	2
Scenario II Jenbacher Engine and Greenhouse	3.72%	2
Scenario III Fuel Cell, Green-Power, No Sale of CO_2	4.21%	2
Scenario IV Fuel Cell, Green Power, Sale of CO_2	42.14%	4

Scale of 0–4, with 4 being the best rating.

The interesting phenomenon that resulted from our hypothetical alternatives to the proposed project at the Groton landfill is that with a possible opening of a market share for "green" power, the sale of such power may bring in substantial revenues when combined with the sale of at least one of the by-products of energy generation from the fuel cell: carbon dioxide. However, markets for both of these commodities are not yet established and this scenario might be an alternative worth exploring for future operations at other landfill sites.

It should be stressed that the proposed project (Scenario I) for the Groton landfill is a pilot project of very limited size and the low rate of return should not discourage other landfill owners from considering this innovative option. On the contrary, if site conditions permit, this scenario might show larger potential for profitability. For example, if the assumptions applied to Groton's three-acre operations are extended to a ten and fifteen acre greenhouse scenario, the rates of return increase to 7.4% and 8.14% respectively. Thus, the importance of the Groton pilot project would not lie in the manifestation of significant commercial profits from this gas-to-energy project involving the operation of hydroponic greenhouse, but rather in the demonstration of the feasibility of such an initiative. In this context, non-economic benefits from the project become important and need to be incorporated in the overall analysis of each possible alternative. The following section will describe the consideration of non-price factors when doing an integrated analysis of a project proposal.

Thus, the importance of the Groton pilot project would not lie in the manifestation of significant commercial profits from this gas-to-energy project involving the operation of hydroponic greenhouse, but rather in the demonstration of the feasibility of such an initiative.

Environmental and Social Matrix Evaluation

The impacts of each scenario were scored from zero to four, according to the following scale: a zero score signifies an extremely negative evaluation and a score of four reveals a low impact or an exemplary evaluation. The scores for each impact, as measured throughout the three life-stages of each scenario, were averaged and a final score tallied. It can be inferred, then, that the scenario with the highest final score has the fewest overall negative implications associated with its implementation.

The criteria, outlined in Appendix B, allow us to standardize our scoring across scenarios. They were set up to be specific to each element of the matrix, and indicate what should be met in order for an attribute to receive a particular score (Graedel 1997).

Our analysis compares each of the scenarios to a baseline reference condition. By comparing the differences from the common baseline, the relative merits of each scenario can be evaluated with respect to the baseline and relative to each other. The baseline condition here is operating a flare at the landfill site, thereby burning all of the landfill gas.

SCENARIO I – FUEL CELL WITH GREENHOUSE GROWING TOMATOES

Table 2 Natural Resource and Land Use: Scenario I

	Life Stage 1	Life Stage 2	Life Stage 3
Land Use	3	4	3
Natural Resource Use	2	4	3
Energy Consumed	2	0	3
Averages	2.25	2.75	3

The greenhouse at Groton will be built on 3.5 acres of an existing paved surface, meaning that there would be no destruction of natural habitats or greenfields. Consequently, land use received a high score. We anticipate some solid debris accumulation in Life Stage 3, necessitating disposal, thus adversely affecting land somewhere to a small degree. There will be a mixture of virgin and recycled materials used in the construction of the greenhouse; therefore, we have given this stage a score of 2. Overall energy consumed in this scenario is high in order to sustain the greenhouse and support the additional transportation requirements to ship the tomatoes; therefore, during operation and maintenance a score of zero was assigned.

Table 3 Waste Generated: Scenario I

	Life Stage 1	Life Stage 2	Life Stage 3
Greenhouse Gases (CO_2 and Methane)	0	4	3
Other Emissions (NO_X, SO_X, hydrocarbons)	2	1	3
Solid Debris	2	4	3
Waste Water	4	4	4
Averages	2	3.25	3

Prior to the installation of the fuel cell and construction of the proposed greenhouse, landfill gas had been burned and the resulting CO_2 vented into the atmosphere. Operation of the greenhouse would result in a net loss of CO_2 as the gas is sequestered in the plants, although building the facility may cause temporary increases in emissions as construction is an energy-intensive process and CO_2 is often a waste product of energy production. It is expected that once the LFG runs out at the end of the project life, less methane or CO_2 will be emitted to the atmosphere.

Other air pollutant emissions are also expected to rise as construction occurs, and such emissions are likely to increase during shipment of the tomatoes. Construction is expected to produce considerable solid waste; however, the operation of the greenhouse should produce little, if any, and the facility's components will likely be recycled at the end of its life. This scenario, like every other scenario, produces very little liquid waste.

A greenhouse will provide additional employment opportunities and therefore receives a high score. In addition, because of the nature of a greenhouse and its physical layout, it will provide a work place accessible to handicapped employees. Public image was given a high score because it is quite positive in this scenario for many reasons. First, green power replaces polluting sources of energy such as coal and oil. Second, the partnerships between the town of

Table 4 Aggregate Societal Implications: Scenario I

	Life Stage 1	Life Stage 2	Life Stage 3
Additional Employment Opportunities	4	4	4
Public Image (green marketing, handicapped employment, closing the loop, partnering	4	4	3
Legal Encumbrances	0	2	3
Averages	2.75	3.25	3.25

Groton, Northeast Utilities, and the tomato grower allow benefits to be experienced by all parties. Third, the experimental nature of this endeavor in the field of industrial ecology allows us to close the loop and reduce emissions and energy lost from the system. Although tomatoes grown using fuel from a landfill may cause some consumers to distrust the cleanliness of the system and be averse to buying such tomatoes, we felt that this notion would be sufficiently offset by the aforementioned public perceptions.

In the initial stage, this scenario poses significant legal challenges. The chief concerns driving the zero (0) score in the first Life Stage are problems associated with creating a binding agreement between the parties, and regulatory obstacles. As noted earlier, permitting here poses significant problems. Life Stage 2 poses less legal risk; however, general liability concerns associated with running a greenhouse seem to justify a score of two (2).

SCENARIO II – INTERNAL COMBUSTION, GREENHOUSE WITH TOMATOES:

Table 5 Natural Resource and Land Use: Scenario II

	Life Stage 1	Life Stage 2	Life Stage 3
Land Use	3	4	3
Natural Resource Use	2	4	3
Energy Consumed	2	0	3
Averages	2	2.75	3

The land use scores, throughout the life cycle, mirror those scores assigned to land use in Scenario I, which also entails building a greenhouse. Similarly, natural resource use will parallel the scores for land use. Energy consumed is quite high during the operation and maintenance life stage because of needs of the greenhouse and the energy needed to run the internal combustion engine that converts the methane to electricity.

Table 6 Waste Generated: Scenario II

	Life Stage 1	Life Stage 2	Life Stage 3
Greenhouse Gases (CO_2 and Methane)	0	4	3
Other Emissions (NO_X, SO_X, hydrocarbons)	2	0	3
Solid Debris (greenhouse and other)	2	4	3
Waste Water	4	4	4
Averages	2	3	3.25

Like Scenario I, landfill gas was burned before the project was up and running. Here, as before, operation of the greenhouse would result in a net loss of CO_2 as the gas is sequestered in the plants, although building the facility may cause temporary increases in emissions during construction. Similarly, other air pollutant emissions are also expected to be higher as construction occurs, and such emissions are also likely to rise as the produce is transported. However, this scenario is complicated by the additional release of nitrous oxides (NOx), during the operation of the Jenbacher engine. As before, construction is expected to produce considerable solid waste, but the operation of the greenhouse should produce little, if any, and the facility's components will likely be recycled at the end of its life. This scenario produces very little liquid waste.

Table 7 Aggregate Societal Implications: Scenario II

	Life Stage 1	Life Stage 2	Life Stage 3
Additional Employment Opportunities	3	4	3
Public Image (green marketing, handicapped employment, closing the loop, partnering	2	2	2
Legal Encumbrances	1	2	3
Averages	2	2.75	2.75

A greenhouse will provide additional employment opportunities to the town and therefore receives a high score. In addition, because of the nature of greenhouse and its physical layout, it will provide a work place conducive to handicapped employment. Public image was given a lower score than Scenario I, which also includes a greenhouse, because although it using a renewable energy source (methane), it requires burning and emissions from the internal combustion engine. Also, it does not quite close the loop, because the CO_2 cannot be captured to use in the greenhouse. The partnerships still exist between the town of Groton, Northeast Utilities, and the tomato growing business, providing opportunities with dispersed benefits. Again, tomatoes grown using fuel from a landfill may cause some consumers to distrust the cleanliness of the system and be adverse to buying such tomatoes.

Like Scenario I, the initial stage poses significant legal challenges. Here, the problems seem to stem more from the troubles associated with creating a binding agreement between the parties as opposed to regulatory obstacles. Although permitting here poses significant barriers, it is expected that regulators would have more familiarity with this more conventional mode of power generation. As before, Life Stage 2 poses less legal risk; however, general liability concerns associated with running both the greenhouse and a mechanical engine seem to justify a score of two (2).

SCENARIO III – GREEN POWER, NO GREENHOUSE, NO SALE OF CO_2

Table 8 Natural Resource and Land Use: Scenario III

	Life Stage 1	Life Stage 2	Life Stage 3
Land Use	3	4	4
Natural Resource Use	3	4	3
Energy Consumed	3	4	3
Averages	3	4	3.25

Again, there is very little need for land and the score throughout the life cycle is 4. Also, after initial construction of the building needed to support the fuel cell and the gas cleaning process, not many natural resources will be needed to sustain this system. Total energy consumed is also very low; therefore, the score we assigned to Energy Consumption is higher than the first two scenarios.

Table 9 Waste Generated: Scenario III

	Life Stage 1	Life Stage 2	Life Stage 3
Greenhouse Gases (CO_2 and Methane)	0	0	3
Other Emissions (NO_X, SO_X, hydrocarbons)	3	4	3
Solid Debris (greenhouse and other)	2	4	3
Waste Water	4	4	4
Averages	2.25	3	3.25

Like the other scenarios, landfill gas is burned before the project is built. Here, there is no greenhouse, so CO_2 will be emitted to the atmosphere during Life Stage 2. Air pollutant emissions are also expected to increase during construction, but because no greenhouse is being built, the emissions are likely to be moderate. There are no releases associated with producing electricity or transporting produce during Life Stage 2. As before, construction is expected to produce considerable solid waste, but the fuel cell will produce none. The fuel cell's components will likely be recycled at the end of its life. This scenario produces very little liquid waste.

Table 10 Aggregate Societal Implications: Scenario III

	Life Stage 1	Life Stage 2	Life Stage 3
Additional Employment Opportunities	2	0	1
Public Image (green marketing, handicapped employment, closing the loop, partnering	2	2	2
Legal Encumbrances	2	3	3
Averages	2	1.75	2

This scenario receives extremely low scores for additional employment opportunities, especially during the operation and maintenance life stage. There will be some jobs created during the construction of the engines and the disassembly. Public image is significantly lower than the previous two scenarios because the methane is being used as green power; we would not be closing the loop because the excess CO_2 would escape into the atmosphere. Also, there would be no public and private partnership involved in this scenario that would allow for the potential for increased benefits to all parties.

Like the other scenarios, the initial stage poses significant legal challenges. However, the problems for this scenario come more from regulatory obstacles. The utility would be the only party here, obviating the need for any complex agreement. Once permitting has been accomplished, Life Stage 2 poses little legal risk. A score of three was assigned because one can never truly eliminate risk.

SCENARIO IV - GREEN POWER, NO GREENHOUSE, NO SALE OF CO_2

Table 11 Natural Resource and Land Use: Scenario IV

	Life Stage 1	Life Stage 2	Life Stage 3
Land Use	3	4	4
Natural Resource Use	3	2	3
Energy Consumed	3	2	3
Averages	3	2.75	3.25

Minimal land will be necessary to satisfy the requirements of this scenario and a score of 4 was assigned to land use throughout the life cycles. Some natural resources will be consumed in the bottling and transport of the CO_2, as will energy throughout the life cycle stages of this scenario.

Table 12 Waste Generated: Scenario IV

	Life Stage 1	Life Stage 2	Life Stage 3
Greenhouse Gases (CO_2 and Methane)	0	2	3
Other Emissions (NO_X, SO_X, hydrocarbons)	3	0	3
Solid Debris (greenhouse and other)	2	3	3
Waste Water	4	4	4
Averages	2.25	2.25	3.25

Landfill gas is burned before the project is built, necessitating the score of zero. Here, the CO_2 is trapped and bottled. Although some CO_2 may be used in applications where it is sequestered, it is expected that most of the CO_2 will eventually be emitted to the atmosphere during Life Stage 2, since the consumers of the gas are expected to be soft drink bottlers. Air pollutant emissions are also expected to increase slightly during construction (no greenhouse being built), but the emissions from Life Stage 2 are expected to be high. Bottling and transporting the CO_2 is expected to release large quantities of air pollutants during Life Stage 2. As before, construction is expected to produce considerable solid waste, but the fuel cell will produce none during Life Stage 2. The bottling operation may produce some. The facility's components will likely be recycled at the end of its life. This scenario produces very little liquid waste.

Table 13 Aggregate Societal Implications: Scenario IV

	Life Stage 1	Life Stage 2	Life Stage 3
Additional Employment Opportunities	2	1	1
Public Image (green marketing, handicapped employment, closing the loop, partnering	3	3	3
Legal Encumbrances	1	2	3
Averages	2	2	2

There will be a very small amount of additional employment spurred on by this scenario from the CO_2 selling business. Again, the public image is mostly positive and receives a score of 3. Although it is not as innovative as the greenhouse scenario, it is also attempting to close the loop of a system. Since all of the CO_2 emitted from the fuel cell will be sold, the private and public partnerships still exist. There will not be the opportunity to hire handicapped employees. CO_2 serves a different market than tomatoes in the winter, but still serves an important niche, namely the beverage industry that relies on CO_2.

Like the other scenarios, the initial stage poses significant legal challenges. Here, like Scenario III, the risks seem associated with regulatory obstacles. The utility would be the only party here, unless it chose to bring in an outside firm to bottle the CO_2. Once permitting has been accomplished, Life Stage 2 poses some legal risk. It would seem that bottling CO_2 has inherent dangers associated with it, resulting in a score of two. Little risk is posed in Life Stage 3.

RESULTS AND DISCUSSION OF ENVIRONMENTAL AND SOCIAL MATRIX EVALUATION

Table 14 shows the final scores of the matrices for the four scenarios (the final matrices for the four scenarios can be found in Appendix C). The left-hand column contains the unweighted matrices. The right column reflects the scores after weighting Life Stage 2 by a factor of five. We weighted this life stage heavily because of the increased impact it had on the overall life cycle of the system relative to the first and third life stages.

Table 14 Total Scores from Environmental and Social Matrices

Scenario	No Weights 48 Points Possible	Life Stage 2-x5 112 Points Possible
Scenario I- Fuel Cell and Greenhouse	31.5	76.5
Scenario II- Jenbacher and Greenhouse	29.75	71.75
Scenario III- Fuel Cell, Green Power, No Sale of CO_2	30.5	73.5
Scenario IV- Fuel Cell, Green Power, CO_2 Sale	35	79

It is evident that weighting Life Stage 2 did not significantly change the relative scores of the final matrices. Based on our analyses, we would suggest that Scenario IV, the fuel cell providing green power to the electrical grid and selling the CO_2, be implemented. Both of this scenario's economic and environmental analyses proved to be more positive than other scenarios.

It can be observed, however, that the final scores of the scenarios were very close and this is probably due to the similarity of the scores of both the natural resource and land use attributes and the aggregate societal implications. At larger sites the effects of economics of scale would significantly change the matrix scores because of the increased stress on natural resources and land, and increased revenue from growing more tomatoes, for example.

CONCLUSIONS

Conceptually, the idea of using LFG to produce electricity, heat, and CO_2 to power a commercial greenhouse is brilliant in its use of all the flows, and admirable from an environmental and industrial ecology viewpoint. Practically speaking, however, translating the concept into reality requires not only the cooperation and commitment from the parties pursuing the project, but also demands a careful economic, social, and legal analysis to ensure its feasibility.

In the near term, with regard to the cooperation and commitment required of the parties, we recognize and urge NU/CL&P to consider several recommendations. First, the present agreement between NU/CL&P and the town of Groton is above and beyond that which is needed to guarantee the town's enthusiasm toward this project. If the terms of this agreement can be offered to other towns, NU or another utility company should have no problem replicating this project at other locations. Second, NU should seriously consider making the expert company a co-owner of GENCO in order to ensure the high level of dedication that only an ownership interest can inspire. Finally, NU needs to be aware of the potential concessions that might have to be offered to any grower considering this project. Those concessions include a willingness to commit to a range of rates for the flows regardless of their actual production costs, a willingness to provide a steady supply of the flows even if the GPU or the fuel cell system are not functioning properly, and a willingness to cooperate in a plan for the grower after the LFG is exhausted. The long-term aspects of this project point toward a more streamlined development process.

The four scenarios examined in this paper exhibited comparable rates of return with the exception of Scenario IV, which envisioned the operation of the fuel cell and the sale of "green" power and carbon dioxide. This alternative was the economic winner due to the low capital costs as compared to the scenarios involving greenhouse construction. It also benefits from revenues from the sale of the carbon dioxide generated along with electricity from the fuel cell. Although this scenario does not provide full closure of the loop – i.e., one of the by-products of energy generation (heat) escapes into the environment – it makes an attempt to utilize as many residues from the industrial process as possible. In the analysis of this scenario, the sale of CO_2 has only been examined as a commercially viable operation at the Groton site. However, in the presence of other industrial facilities in the vicinity, this scenario might be expanded to include the delivery of heat as an input for operations and could provide an economically attractive alternative grounded in industrial ecology principles.

The proposed pilot project for Groton landfill shows a low rate of return (3.85%), but this is largely due to the limited size and scope of the project. If the assumptions applied to Groton's three-acre operations are extended to a ten and fifteen acre greenhouse scenario, the rates of return increase to 7.4% and 8.14% respectively. Moreover, if there were changes in the average price of tomatoes, the rate of inflation, or the annual yield of 830,000 pounds from three acres, the profitability of the project would change as well. Thus, Scenario I is likely to become a commercially viable option if scaled up and even more so if produce yields exceed the assumed quantities.

In conclusion, based on the final scores of our analysis, we would recommend that the parties implement Scenario IV. It presents the best balancing of economic, social, and environmental aspects and furthers the principles of industrial ecology. "Closing the loop" may be this project's long-term contribution to future such private and public partnerships.

REFERENCES

Graedel, T.E. 1997. *Streamlined Life-Cycle Assessment.* Prentice Hall, Upper Saddle River, New Jersey.

Graedel, T.E., B.R. Allenby, and P.R. Comrie. 1995. Matrix Approaches to Abridged Life Cycle Assessment. *Environmental Science and Technology* Volume 29, No. 3.

International Fuel Cells. The Fuel Cell. Undated company materials.

Northeast Utilities (NU) website. Accessed 1998. http://www.nu.com/aboutNU/restruct/elecwork.htm

Northeast Utilities (NU), International Fuel Cells Corporation, and U.S. Environmental Protection Agency (EPA). Operating a Fuel Cell Using Landfill Gas. Undated company publication.

Reduction Investment Proposal for GENCO. June 1, 1997. Unpublished draft proposal on file with the authors.

Restructuring Bill. 1998. An Act Concerning Electric Restructuring. Substitute House Bill No. 5005, Public Act 98-28. April 15, 1998.

U.S. Environmental Protection Agency (EPA). 1996. *Turning a Liability into an Asset: A Landfill Gas-to-Energy Development Handbook.* Landfill Methane Outreach Program. September 1996.

APPENDIX A

Scenario 1 Assumptions

Capital Cost	
Fuel Cell	[illegible]
Engine	N/A
Engine Cost	N/A
Fuel Cell:	
Gross Station Capacity	[illegible] KW
Heat Rate	[illegible]
Net After Load	[illegible] KW
Availability	[illegible]
Annual Power	[illegible] KWH
Heat Output	[illegible]
[illegible]	
Gross Station Capacity	[illegible] KW
[illegible] Heat Rate	[illegible]
Availability	[illegible]
Net After Load	[illegible]
Net Annual Power	[illegible]
[illegible]	[illegible]
Greenhouse Construction	
Land	[illegible]
Excavation & Backfill	[illegible]
Sand	[illegible]
PVC Sheeting	[illegible]
Paved roads & parking	[illegible]
Gas Hookup	$0
Water Hookup	$0
Electricity Hookup	$0
Total Land	[illegible]
Building	[illegible]
Total Greenhouse Cost	[illegible]
Greenhouse Equity %	[illegible]
Greenhouse Equity	[illegible]
Greenhouse Debt	[illegible]
Greenhouse Loan Term	[illegible]
Greenhouse Loan Rate	[illegible]
[illegible]	[illegible]

Revenue & Expense Data

GENCO		
Revenue		
Electricity Sales Rate	[illegible]	KWH
Rate Escalation	[illegible]	Per Annum
Heat Sales	[illegible]	Per MMBTU
[illegible] Rate Escalation	[illegible]	per annum
		Per MMBTU
Expenses		
O&M Costs - [illegible]	[illegible]	per KWH
O&M Costs - Fuel Cell	[illegible]	per KWH
Capital Replacement Fuel Cell	[illegible]	per KWH
Insurance	[illegible]	per annum
Administration	[illegible]	per annum
Property Taxes	[illegible]	per annum
Expense Escalation	[illegible]	per annum
Lease Payments		per annum
[illegible]		
[illegible]		
Gas Fuel	$4.50	per MMBTU
Natural Gas [illegible] Conversion	[illegible]	
Fuel Cell [illegible]	[illegible]	

Financial Data

Estimated Construction/Acquisition Costs	
[illegible]	[illegible]
[illegible]	[illegible]
Total Project Cost	[illegible]
GENCO Equity & Financing Terms	
Equity Required	[illegible]
Equity	[illegible]
Loan Amount	[illegible]
Term in Years	[illegible]
Interest Rate Per Annum	[illegible]
[illegible] Equity & Financing Terms	
Equity Required	[illegible]
Equity	[illegible]
Loan Amount	[illegible]
Term in Years	[illegible]
Interest Rate Per Annum	[illegible]
Total Project Equity & Financing Terms Summary	
Equity Required	[illegible]
Loan Amount	
Total Project Cost	[illegible]
Other	
Book Depreciation	
[illegible] Straight Line Depreciable Life	[illegible]
[illegible] Straight Line Depreciable Life	[illegible]
Tax Depreciation Fixed Assets	
[illegible] Straight Line Depreciable Life	[illegible]
[illegible] Straight Line Depreciable Life	[illegible]
Tax Depletion of [illegible] Gas Rights	
Purchase Price of Gas Rights	
Depletion Life	[illegible]
Income Tax Rate	[illegible]

[illegible]		
Wellfield and Gas Rights		
Wellfield Purchase Price	[illegible]	
Gas Rights Purchase Price		
Total Purchase Price	[illegible]	
Revenue		
[illegible]		
[illegible] Sales Rate	[illegible]	per MMBTU
[illegible] Sales Rate Escalation	[illegible]	per annum
Section 29 Credit		
[illegible] Tax Credit Rate	[illegible]	per MMBTU
Tax Credit Escalation	[illegible]	per annum
[illegible]	[illegible]	
[illegible]	[illegible]	
Expenses		
O&M Cost	[illegible]	per MMBTU
Insurance	[illegible]	per annum
Administration	[illegible]	per annum
Property Taxes	[illegible]	per annum
Water Disposal	[illegible]	per annum
[illegible] Rental	[illegible]	Per Annum
Expense Escalation	[illegible]	per annum
Tax Depreciation - Wellfield	[illegible]	Years
Tax Depletion - Gas Rights	[illegible]	Years

Greenhouse Operations		
Construction		
Cost	[illegible]	Per SF
Building Size	[illegible]	Acres
Area	[illegible]	SF
Revenue		
[illegible]	[illegible]	[illegible]
Sales Price - [illegible]	[illegible]	per LB
Sales Price Escalation	[illegible]	per annum
Expenses		
[illegible] O&M Costs	[illegible]	per year
Insurance	[illegible]	per annum
Labor	[illegible]	Per Acre
[illegible]	[illegible]	Per Acre
Administration	[illegible]	per annum
[illegible] Rate	[illegible]	
Property Taxes	[illegible]	per annum
[illegible]	[illegible]	Per annum
CO_2	[illegible]	Per Acre/Yr
Greenhouse Heat	[illegible]	MMBTU/Acre/Yr
[illegible]	[illegible]	per year
[illegible]	[illegible]	Per MMBTU
[illegible]	[illegible]	
Electricity Needed	[illegible]	KWH/[illegible]
Purchased Power Rate	[illegible]	Per KWH
Expense Escalation	[illegible]	per annum
[illegible] Escalation	[illegible]	per annum
Tax Depreciation - Wellfield	[illegible]	Years
Tax Depletion - Gas Rights	[illegible]	Years

APPENDIX A, continued

Scenario I Cash Flows

GENCO

YEAR	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
KWH Sold Fuel Cell	832,200	832,200	832,200	832,200	832,200	832,200	832,200	832,200	832,200	832,200	832,200	832,200	832,200	832,200	832,200
Annual KWH Sold	832,200	832,200	832,200	832,200	832,200	832,200	832,200	832,200	832,200	832,200	832,200	832,200	832,200	832,200	832,200
Revenues															
Electricity sales	48,517	48,517	48,517	48,517	48,517	48,517	48,517	48,517	48,517	48,517	48,517	-	-	-	-
Heat Sales	43,263	44,128	45,011	45,911	46,829	47,766	48,721	49,696	50,689	51,703	52,737	53,792	54,868	55,965	57,085
CO2 Sales	90,000	91,800	93,636	95,509	97,419	99,367	101,355	103,382	105,449	107,558	109,729	111,904	114,142	116,425	118,751
Total Revenues	181,780	184,446	187,164	189,937	192,765	195,650	198,593	201,595	204,656	207,779	210,964	165,696	169,010	172,390	175,838
Operating Expenses															
LFG Fuel Cost	35,630	35,990	36,710	37,444	38,193	38,957	39,736	40,531	41,341	42,168	43,011	43,872	44,749	45,644	46,557
Natural Gas	41,492	44,352	45,239	46,144	47,067	48,008	48,968	49,948	50,947	51,966	53,005	54,065	55,146	56,249	57,374
O&M Expense - GENSET	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
O&M Expense - Fuel Cell	8,323	8,398	8,658	8,831	9,008	9,188	9,372	9,559	9,751	9,946	10,144	10,347	10,554	10,765	10,980
Capital Costs Fuel Cell	8,322	8,322	8,322	8,322	8,322	8,322	8,322	8,322	8,322	8,322	8,322	8,322	8,322	8,322	8,322
Insurance	2,500	2,550	2,601	2,653	2,706	2,760	2,815	2,872	2,929	2,988	3,047	3,108	3,171	3,234	3,299
Administrative	5,000	5,100	5,202	5,306	5,412	5,520	5,631	5,741	5,858	5,975	6,095	6,217	6,341	6,468	6,597
Property Taxes	10,000	10,200	10,404	10,612	10,824	11,041	11,262	11,487	11,717	11,951	12,190	12,434	12,682	12,936	13,195
Total Operating Expense	113,426	115,003	117,136	119,302	121,532	123,796	126,106	128,452	130,864	133,313	135,815	138,365	140,966	143,619	146,325
Operating Cash Flows	**68,354**	**69,443**	**70,028**	**70,635**	**71,233**	**71,854**	**72,487**	**73,133**	**73,792**	**74,464**	**75,149**	**27,331**	**28,044**	**28,771**	**29,513**

GASCO

YEAR	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
MMBTUs to GENCO LFG	105,200	105,200	105,200	105,200	105,200	105,200	105,200	105,200	105,200	105,200	105,200	105,200	105,200	105,200	105,200
MMBTU Collected	105,200	105,200	105,200	105,200	105,200	105,200	105,200	105,200	105,200	105,200	105,200	105,200	105,200	105,200	105,200
Revenues															
LFG Sales	35,630	35,990	36,710	37,444	38,193	38,957	39,736	40,531	41,341	42,164	43,011	43,872	44,749	45,644	46,557
Section 29 Sales	111,722	115,074	118,526	122,082	125,745	129,517	133,402	137,404	141,527	145,772					
Total Revenues	147,522	151,064	155,236	159,526	163,937	168,474	173,138	177,935	182,868	187,940	43,011	43,872	44,749	45,644	46,557
Operating Expenses															
O&M Expenses	26,500	26,760	26,826	27,363	27,910	28,469	29,037	29,618	30,210	30,815	31,431	32,060	32,701	33,355	34,022
Insurance	2,500	2,550	2,601	2,653	2,706	2,760	2,815	2,872	2,929	2,988	3,047	3,108	3,171	3,234	3,299
Administrative	5,000	5,100	5,202	5,306	5,412	5,520	5,631	5,741	5,858	5,975	6,095	6,217	6,341	6,468	6,597
Property Taxes	2,000	2,040	2,081	2,122	2,165	2,208	2,252	2,297	2,343	2,390	2,438	2,487	2,536	2,587	2,639
Production Royalty			-	-			-		-		-		-	-	-
Water Disposal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	35,630	35,990	36,710	37,444	38,193	38,957	39,736	40,531	41,341	42,168	43,011	43,872	44,749	45,644	46,557
Operating Cash Flow	**111,722**	**115,074**	**118,526**	**122,082**	**125,745**	**129,517**	**133,402**	**137,404**	**141,527**	**145,772**	-	-	-	-	-

[illegible]

Greenhouse

YEAR	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Lbs Sold	630,000	630,000	630,000	630,000	630,000	630,000	630,000	630,000	630,000	630,000	630,000	630,000	630,000	630,000	630,000
Revenues															
Sale of Tomatoes	1,012,500	1,058,250	1,075,465	1,102,001	1,120,621	1,145,484	1,168,591	1,190,791	[illegible]	1,239,966	1,264,707	1,290,001	1,315,801	1,342,117	1,368,959
Total Revenues	1,012,500	1,058,250	1,075,465	1,102,001	1,120,621	1,145,484	1,168,591	1,190,791	[illegible]	1,239,966	1,264,707	1,290,001	1,315,801	1,342,117	1,368,959
Operating Expenses															
Labor	225,000	229,500	234,090	238,772	243,547	248,408	253,387	258,455	263,624	268,896	274,274	279,759	285,354	291,061	296,882
Cost of Goods Sold	153,600	156,672	159,145	162,868	165,612	168,924	172,303	175,749	179,264	182,849	186,506	190,236	194,041	197,922	201,880
Hot Boiler O&M Costs	73,000	74,460	75,949	77,468	79,018	80,598	82,210	83,854	85,531	87,242	88,987	90,766	92,582	94,433	96,322
Insurance	2,500	2,550	2,601	2,653	2,706	2,760	2,815	2,872	2,929	2,988	3,047	3,108	3,171	3,234	3,299
Administration	5,000	5,100	5,202	5,306	5,412	5,520	5,631	5,743	5,858	5,975	6,095	6,217	6,341	6,468	6,597
Property Tax	38,163	38,927	39,716	40,500	41,310	42,136	42,979	43,838	44,715	45,610	46,521	47,452	48,401	49,369	50,356
Ground Lease	25,000	25,500	26,010	26,530	27,061	27,602	28,154	28,717	29,291	29,877	30,475	31,084	31,706	32,340	32,987
CO2	90,000	91,800	93,636	95,509	97,419	99,367	101,355	103,382	105,449	107,558	109,709	111,904	114,142	116,425	118,753
Heating Costs	35,630	35,990	36,710	37,444	38,193	38,957	39,736	40,531	41,341	42,168	43,011	43,872	44,749	45,644	46,557
Electricity Credit	48,517	48,517	48,517	48,517	48,517	48,517	48,517	48,517	48,517	48,517	48,517	0	0	0	0
Electricity Costs	211,775	217,062	219,412	240,827	244,245	246,697	249,154	251,646	254,162	256,704	259,271	261,863	264,482	267,127	269,798
Total Operating Expense	930,896	945,466	961,074	976,868	991,0[illegible]	1,009,488	1,026,2[illegible]	1,043,[illegible]	[illegible]	1,074,384	[illegible]	1,064,262	[illegible]	[illegible]	1,123,415
Operating Cash Flows	**106,604**	**112,584**	**118,001**	**124,133**	**129,984**	**135,996**	**142,153**	**148,458**	**154,914**	**161,525**	**168,292**	**225,739**	**230,832**	**236,095**	**245,627**

[illegible]

APPENDIX A, continued

Economic performance results

Scenario I: Fuel Cell and Greenhouse

YEAR	Equity	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
GENSCO		68,354	69,443	[illegible]	70,635	71,211	71,954	72,497	73,113	73,792	74,464	75,149	75,811	76,544	76,771	77,511
GASCO		111,722	115,074	118,526	122,082	125,745	129,517	133,402	137,404	141,527	145,772	0	0	0	0	0
Greenhouse		106,304	112,764	119,551	124,115	129,764	134,996	142,155	148,459	154,814	163,525	168,292	221,739	230,832	240,093	245,527
TOTAL	(1,488,278)	286,381	297,191	[illegible]	316,820	326,261	337,367	348,041	358,996	370,213	383,761	243,441	251,069	246,876	266,805	273,041

Combined ROR	3.85%

Scenario II: Jenbacher Engine and Greenhouse

YEAR	Equity	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
GENSCO		26,169	25,675	24,629	23,540	22,470	21,358	20,224	19,067	17,883	16,685	15,455	(397,245)	(394,525)	(395,526)	(397,155)
GASCO		111,722	115,074	118,526	122,082	125,745	129,517	133,402	137,404	141,527	145,772	0	0	0	0	0
Greenhouse		98,801	104,296	117,451	126,745	136,229	145,893	155,719	165,765	175,967	186,398	597,004	615,257	626,204	637,481	648,068
TOTAL	(3,065,279)	236,712	249,045	260,586	272,355	284,444	295,768	309,355	322,246	335,427	348,855	212,459	222,011	231,744	241,655	251,755

Combined ROR	3.72%

Scenario III: Fuel Cell, "Green" Power, No Sale of CO2

YEAR	Equity	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
GENSCO		(54,494)	(54,181)	(54,806)	(55,200)	(55,591)	(55,975)	(56,340)	(56,712)	(57,067)	(57,109)	(57,749)	(58,057)	(58,361)	(58,649)	(58,925)
GASCO		111,722	115,074	118,526	122,082	125,745	129,517	133,402	137,404	141,527	145,772	0	0	0	0	0
Greenhouse																
TOTAL	(488,090)	57,228	60,093	63,727	66,853	70,151	73,542	77,033	80,691	84,459	88,163	(57,749)	(58,057)	(58,361)	(58,649)	(58,925)

Combined ROR	4.23%

Scenario IV: Fuel Cell, "Green" Power, Sale of CO2

YEAR	Equity	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
GENSCO		65,106	66,207	65,801	65,400	65,000	64,625	64,241	63,867	63,511	63,191	62,860	62,545	62,239	61,951	61,677
GASCO		111,722	115,074	118,526	122,082	125,745	129,517	133,402	137,404	141,527	145,772	0	0	0	0	0
Greenhouse																
TOTAL	(540,866)	177,828	181,281	184,327	187,485	190,751	194,142	197,651	201,271	205,037	208,963	62,860	62,545	62,239	61,951	61,677

Combined ROR	47.14%

APPENDIX B

Criteria for Matrix Scoring

TOTAL	Natural Resource and Land Use	Waste Generated	Economic Factors	Aggregate Societal Implications
Life Stage 1– Development and Realization	1,1	1,2	1,3	1,4
Life Stage 2– Operation and Maintenance	2,1	2,2	2,3	2,4
Life Stage 3– Disposal/Reincarnation	3,1	3,2	3,3	3,4

1,1)
If any of the following apply, the element rating is 0:
Development of a greenfield and exclusive use of virgin materials.
If any of the following apply, the matrix element rating is 4:
Negligible destruction of the natural environment, through the use of existing materials and structures.

1,2)
If any of the following apply, the matrix element rating is 0:
A large quantity of waste (gas, leachate, solid liquid) is generated and there is no recycling or reuse.
If any of the following apply, the matrix element rating is 4:
Insignificant waste is generated and/or significant recovery offsets generated waste.

1,3)
If any of the following apply, the matrix element rating is 0:
When costs exceed benefits.
If any of the following apply, the matrix element rating is 1:
When the project breaks even (zero rate of return (ROR)).
If any of the following apply, the matrix element rating is 2:
When rate of return exceeds inflation rate (>3%).
If any of the following apply, the matrix element rating is 3:
The project ROR meets or exceeds the ROR of an alternative use of capital, assumed to be 6%.
If any of the following apply, the matrix element rating is 4:
When there is a commercially acceptable rate of return (>12%).

1,4)
If any of the following apply, the matrix element rating is 0:
Substantial legal risks and social costs.
If any of the following apply, the matrix element rating is 4:
Negligible legal risks and significant social benefits.

2,1)
If any of the following apply, the element rating is 0:
Exclusive use of virgin materials.
If any of the following apply, the matrix element rating is 4:
Negligible destruction of the natural environment, through the use of existing materials and structures.

2,2)
If any of the following apply, the matrix element rating is 0:
A large quantity of waste (gas, leachate, solid liquid) is generated and there is no recycling or reuse.
If any of the following apply, the matrix element rating is 4:
Insignificant waste is generated and/or significant recovery offsets generated waste.

2,3)
If any of the following apply, the matrix element rating is 0:
When costs exceed benefits.
If any of the following apply, the matrix element rating is 1:
When the project breaks even (zero rate of return (ROR)).
If any of the following apply, the matrix element rating is 2:
When rate of return exceeds inflation rate.
If any of the following apply, the matrix element rating is 3:
The project ROR meets or exceeds the ROR of an alternative use of capital, assumed to be 6%.
If any of the following apply, the matrix element rating is 4:
When there is a commercially acceptable rate of return (> 12%).

2,4)
If any of the following apply, the matrix element rating is 0:
Substantial legal risks and social costs.
If any of the following apply, the matrix element rating is 4:
Negligible legal risks and significant social benefits.

3,1)
If any of the following apply, the element rating is 0:
Exclusive use of virgin materials, no restoration of greenfield conditions and substantial contamination.
If any of the following apply, the matrix element rating is 4:
Negligible destruction of the natural environment, through the use of existing materials and structures.

3,2)
If any of the following apply, the matrix element rating is 0:
A large quantity of waste (gas, leachate, solid liquid) is generated and there is no recycling or reuse.
If any of the following apply, the matrix element rating is 4:
Insignificant waste is generated and/or significant recovery offsets generated waste.

3,3)
If any of the following apply, the matrix element rating is 0:
When costs exceed benefits.
If any of the following apply, the matrix element rating is 1:
When the project breaks even (zero rate of return (ROR)).
If any of the following apply, the matrix element rating is 2:
When rate of return exceeds inflation rate (>3%).
If any of the following apply, the matrix element rating is 3:
The project ROR meets or exceeds the ROR of an alternative use of capital, assumed to be 6%.
If any of the following apply, the matrix element rating is 4:
When there is a commercially acceptable rate of return (>12%).

3,4)
If any of the following apply, the matrix element rating is 0:
Substantial legal risks and social costs.
If any of the following apply, the matrix element rating is 4:
Negligible legal risks and significant social benefits.

APPENDIX C

Environmental and Social Matrix Evaluation

Scenario I – Fuel Cell and Greenhouse

	Natural Resource and Land Use	Waste Generated	Economic Factors	Aggregate Societal Implications	TOTAL
Life Stage 1– Development and Realization	2.25	2	2.75	2	9
Life Stage 2– Operation and Maintenance	2.75	3.25	3.25	2	11.25
Life Stage 3– Disposal/Reincarnation	3	3	3.25	2	11.25
TOTAL	8	8.25	9.25	6	31.5/48

Rounded to the nearest quarter

Scenario II – Jenbacher Engine and Greenhouse

	Natural Resource and Land Use	Waste Generated	Economic Factors	Aggregate Societal Implications	TOTAL
Life Stage 1– Development and Realization	2.25	2	2	2	8.25
Life Stage 2– Operation and Maintenance	2.75	3	2.75	2	10.5
Life Stage 3– Disposal/Reincarnation	3	3.25	2.75	2	11
TOTAL	8	8.25	7.5	6	29.75/48

Rounded to the nearest quarter

Scenario III – Fuel Cell, Green Power, No CO_2 Sale

	Natural Resource and Land Use	Waste Generated	Economic Factors	Aggregate Societal Implications	TOTAL
Life Stage 1– Development and Realization	3	2.25	2	2	9.25
Life Stage 2– Operation and Maintenance	4	3	1.75	2	10.75
Life Stage 3– Disposal/Reincarnation	3.25	3.25	2	2	10.5
TOTAL	10.25	8.5	5.75	6	30.5/48

Rounded to the nearest quarter

Scenario IV – Fuel Cell, Green Power, Sale of CO_2

	Natural Resource and Land Use	Waste Generated	Economic Factors	Aggregate Societal Implications	TOTAL
Life Stage 1– Development and Realization	3	2.25	2	4	11.25
Life Stage 2– Operation and Maintenance	2.75	2.25	2	4	11
Life Stage 3– Disposal/Reincarnation	3.25	3.25	2.25	4	12.75
TOTAL	9	7.75	6.25	12	35/48

Rounded to the nearest quarter

APPENDIX C, continued

Environmental and Social Matrix Evaluation, with Life Stage 2 Weighted

Scenario I Fuel Cell and Greenhouse

	Natural Resource and Land Use	Waste Generated	Economic Factors	Aggregate Societal Implications	TOTAL
Life Stage 1– Development and Realization	2.25	2	2.75	2	9
Life Stage 2*– Operation and Maintenance	13.75	16.25	16.25	10	56.25
Life Stage 3– Disposal/Reincarnation	3	3	3.25	2	11.25
TOTAL	19	21.25	22.25	14	31.5/48

*Weighted by a factor of five

Scenario II - Jenbacher Engine and Greenhouse

	Natural Resource and Land Use	Waste Generated	Economic Factors	Aggregate Societal Implications	TOTAL
Life Stage 1– Development and Realization	2.25	2	2	2	8.25
Life Stage 2*– Operation and Maintenance	13.75	15	13.75	10	52.5
Life Stage 3– Disposal/Reincarnation	3	3.25	2.75	2	11
TOTAL	19	20.25	18.5	14	71.75/112

*Weighted by a factor of five

Scenario III - Fuel Cell, Green Power, No CO_2 Sale

	Natural Resource and Land Use	Waste Generated	Economic Factors	Aggregate Societal Implications	TOTAL
Life Stage 1– Development and Realization	3	2.25	2	2	9.25
Life Stage 2*– Operation and Maintenance	20	15	8.75	10	53.75
Life Stage 3– Disposal/Reincarnation	3.25	3.25	2	2	10.5
TOTAL	26.25	20.5	12.75	14	73.5/112

*Weighted by a factor of five

Scenario IV - Fuel Cell, Green Power, Sale of CO_2

	Natural Resource and Land Use	Waste Generated	Economic Factors	Aggregate Societal Implications	TOTAL
Life Stage 1– Development and Realization	3	2.25	2	4	11.25
Life Stage 2*– Operation and Maintenance	13.75	11.25	10	20	55
Life Stage 3– Disposal/Reincarnation	3.25	3.25	2.25	4	12.75
TOTAL	20	16.75	14.25	28	79/112

*Weighted by a factor of five

The MatchMaker! System: Creating Virtual Eco-Industrial Parks 1997

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ABSTRACT
The virtual eco-industrial park alters the Kalundborg model by allowing firms that are not in proximity with one other to exchange material flows. Bechtel Corporation Research and Development, San Francisco, has studied the Kalundborg model and numerous other eco-industrial parks (EIPs) in order to assess the viability of industrial symbiosis (IS) on a grander scale. A world leader in engineering and design, Bechtel is frequently contracted to build and manage industrial parks on a large scale worldwide. Bechtel has had some success with a prototype virtual eco-industrial project in Brownsville, Texas. Existing material exchanges operate over regions and industries, providing services over the Internet and through books. These services use different material classification systems, making integration difficult.

Our team's project built upon the experience of Brownsville and the material exchanges by designing and creating a new system for matching materials flows. The system uses a material taxonomy which operates in a similar way to the standard industrial classification system (SIC) code hierarchy. The system, called MatchMaker!, is based upon a relational database, providing a path for future development.

MatchMaker! can be used by firms and local authorities to perform material flow analyses over wide geographical areas. Information from New Haven industries has been imported into MatchMaker! from a commercially available CD-ROM, but standard material flow data is insufficient to perform a regional matching exercise.

The next steps examined in this paper are the entry of standard SIC-based material flows into the database, enhancement of the material taxonomy, and eventual ownership of the product. Future visions include the ability to automatically map the material flows, a web-based database, and integration of local, regional, and national eco-industrial parks.

BECHTEL PROJECT

History

Industrial parks have long been utilized as a means for realizing economic advantage. By co-locating, enterprises can reduce the expenses of security, facility maintenance, and perhaps even permitting. Some industrial parks take the community idea a step further by adding a common cafeteria, reprographic facility, or mailroom to their list of common resources. In the typical scheme, however, industrial park members act as solitary individuals. By neglecting the community aspects of co-location, an enterprise may forego the economic advantages of a symbiotic relationship with its neighbors. Such industrial symbiosis (IS) among proximal facilities can provide opportunities for competitive advantage and environmental amelioration. As the evolutionary successor to industrial parks, eco-industrial parks (EIP) go one step further by linking local industries through a cooperative system of material and utilities exchanges.

The industrial community in Kalundborg, Denmark has progressively integrated about a dozen industrial members into an economically viable and environmentally-friendly system. Diverse enterprises have co-located in order to exchange a variety of materials and utilities that would otherwise have been lost or discarded. The paragon EIP, Kalundborg has proven that by "closing the loop," industries can gain competitive advantage, reduce their environmental liabilities, and improve their public image. Through this concerted waste minimization effort, society also benefits from improved economic conditions and reduced natural resource usage, waste generation, and pollution.

The Kalundborg model cannot easily be reproduced throughout the world. The microcosm at Kalundborg was created under a very specific set of political, economic, societal, and environmental circumstances. It is uncertain if and how the EIP would have developed under other conditions. Nevertheless, the Kalundborg scenario demonstrates the feasibility of exchanging utilities, information, and material streams through industrial cooperation.

Bechtel Corporation Research and Development has forseen a competitive edge in developing a tool that can identify IS possibilities in a complex industrial system. This tool could be used to methodically develop EIPs as well as improve the economic and environmental conditions of existing systems.

In its investigations, Bechtel questioned the necessity of co-location for IS to work. If co-location is a critical element of success, Bechtel argued, then the size and scope of an EIP will be limited to the physical size of the park. However, if some waste streams can cost-effectively support their transportation, then a "virtual" EIP (VEIP) could be constructed to include exchanges throughout a city, a region, or perhaps the world.

If some waste streams can cost-effectively support their transportation, then a "virtual" EIP (VEIP) could be constructed to include exchanges throughout a city, a region, or perhaps the world.

The idea for a VEIP was first tested in the Brownsville Regional IS Project. Covering industries in the Brownsville, Texas and Matamoros, Mexico areas, the project provided the opportunity to explore the theory of IS planning throughout a region. Over several months, Bechtel conducted interviews of local area businesses to see what material streams were required or available for exchange.

These data were then assembled in a Microsoft (MS) Excel database. Although very limited in its functionality, Excel was useful as a rudimentary first-generation platform for validating a proof-of-concept model. Another database was constructed that included generic input and output stream data for a large variety of industrial sectors. The input data from existing facilities were then matched against local output data that resulted in a list of potential exchanges for the extant facilities. The matched streams could then be exported into Bechtel's proprietary systems optimization tool (PIMS) to demonstrate how the best solution would be achieved.

The local data were also matched to generic data in hopes of identifying specific industry types for which there might be symbiotic opportunity. By no means the exclusive factor, this local-exchange gap analysis could be included in a decision-maker's evaluation of siting a facility in the area.

Bechtel has envisioned applying this tool worldwide. In addition to Brownsville where key projects have developed such as a new port in Viet Nam, a light industry and airport project in the United Arab Emirates, and the Jubail Industrial Complex in Saudi Arabia. On a national level, Bechtel wanted to test the tool in an urban redevelopment project, and has discussed such a project with interested academic, community, government, and industrial partners to stimulate regional development through IS and IS-related strategic planning in New Haven and Connecticut.

Even with the emigration of some industry, Connecticut still boasts an extensive small-scale industrial base, in addition to a modest population of large manufacturers. In 1994, for example, the EPA processed about 1,000 forms for a total of 359 Connecticut facilities that were required to report Toxics Release Inventories (TRI) under the Clean Air Act Amendments of 1990. With a population of 3,275,000, the state ranked 19th nationally for total intrastate transfers to recycling of the 189 reported chemicals. On-site, almost 40 million pounds of chemicals were either combusted for energy recovery or otherwise treated. Off-site transfers for recycling, energy recovery, treatment, and disposal exceeded 35.6 million pounds. Since the bulk of these chemicals are typical industrial solvents (e.g. methanol, dichloromethane, toluene, etc.), it is distinctly possible that many of these and other "wastes" could serve as useful input streams to local area business.

THE CONTEXT: EXISTING MECHANISMS

Waste Exchanges

Since the dawn of the industrial era, formal mechanisms have been employed to reclaim waste products and deliver them to end users who value them as commodities. Scrap yards, recycling centers, dealers, and brokers have historically served as middle-men, providing indirect linkages between generators and users of waste materials.

For some commodities, such as machinery and scrap metal, the middleman pays the generator for the waste material and then sells the material to an end user. For other commodities, such as chemical wastes and certain grades of glass and paper, the generator will pay the middle-man to accept the waste product rather than pay expensive disposal fees elsewhere. Sophisticated markets have developed for waste commodities such as scrap metal, paper, glass, cardboard, wood, rubber, and plastics. Market prices are reported in trade journals like the Recycling Times, and some exchanges are coordinated in formal markets such as the Chicago Board of Trade Recyclables Exchange.

In the mid-1970s, a new mechanism emerged to coordinate materials exchanges. Organizations known as "waste exchanges" sought to broaden the spectrum of materials available for exchange beyond those traded in formal markets and arranged for by brokers. Unlike the middle-men who often receive materials and resell them, waste exchange organizations serve only as information brokers helping generators and end users to find each other.

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We spoke with the heads of several waste exchanges in the United States and Canada who describe their roles as collecting information about materials available from generators or wanted by end users and disseminating that information as widely as possible. Most waste exchange organizations follow a database model quite similar to the classified ads one sees in a local newspaper. Generators place ads for available materials into general categories such as acids, alkalis, solvents, metals, and plastics. End users can search the listings for materials of interest or place "wanted" ads for materials they are seeking.

About 15 waste exchanges across North America provide on-line catalogs searchable by category or keyword. While many of the on-line exchanges are accessible on the World Wide Web, a few are maintained as private computer bulletin board systems that must be dialed directly. Both the on-line exchanges and the off-line exchanges publish printed catalogs of materials available and materials wanted. Most of the exchanges allow for generators and users to place ads anonymously, but the exchange operators usually encourage participants to disclose their identities in the listings.

The majority of current waste exchange organizations are non-profits or quasi-governmental entities operating under the auspices of local departments of environmental protection. These exchanges tend to limit their geographic outreach to a single state or county. A small number of exchanges are owned and operated by industry groups such as the European Plastics Converters Association and by waste generators themselves such as Siemens of Germany.

Funding for most waste exchanges comes from government grants or incentive payments based upon the quantity of waste disposal averted by the waste exchange service. Additional revenue comes from fees paid by parties placing ads, subscription sales of the catalog or on-line service, and fees paid by generators or end users upon successful completion of a match.

Fragmented by region or by industrial sector, the current waste exchanges are ill equipped to take advantage of the opportunities for long-distance or cross-sector transfers. There has been some effort among the on-line exchanges to pool their listings, but the lack of standardization has been a stumbling block.

Limitations of Waste Exchanges

While waste exchange organizations have been quite successful at averting unnecessary disposal and encouraging symbiotic industrial relationships, the organizations face several limitations. Fragmented by region or by industrial sector, the current waste exchanges are ill equipped to take advantage of the opportunities for long-distance or cross-sector transfers. There has been some effort among the on-line exchanges to pool their listings, but the lack of standardization has been a stumbling block.

Arrowwood Associates, an Indiana-based consulting firm, has developed Arrowwood Market, a database system for managing waste exchange organizations. For a fee, Arrowwood pools the databases of multiple exchanges using the Arrowwood Market software and allows for long-distance matching. Relatively few waste exchanges are currently using Arrowwood Market, and it remains to be seen if it will emerge as the industry standard.

Since most waste exchanges group listings into large, general categories such as acids and alkalis, many potential end users have difficulty locating materials that may be of use to them. Listings may be hundreds of pages long, and some end users report that the search process is more trouble than it is worth. Some of the on-line services provide keyword matching and most of the other exchanges can perform simple keyword searches for people who phone with a specific request. This keyword searching, however, is frequently complicated by the lack of standardization of material descriptions in the listings. The Arrowwood Market software creates a small taxonomy with general categories such as oil or plastics and sub-categories such as PET or HDPE plastic. These categories are often still too general to permit an automated matching process.

The existing waste exchanges are poorly suited for proactive matching, co-location, or gap analysis. As the exchanges focus upon materials available and materials wanted, the databases are of no use in matching non-specified material flows. Exchanges are unable to match generators and end users for commodities such as steam or water. And because the exchanges do not track extensive flow information, they cannot proactively recommend potential matches based upon industry averages for firms that have not included their own materials listings.

Conventional EIPs

Providing economic advantages through proximal IS, EIPs entice responsible and interested industries to co-locate. The newly constructed system should be a well-balanced mix of businesses in which the aggregate input and residual streams of the assembled system are significantly lower than the sum of the disaggregated entities. Furthermore, previously unidentified dissipative waste streams, such as latent heat, non-contact cooling water, or pressurized steam, can similarly be exchanged to provide improved economic efficiencies while decreasing the consumptive reliance on natural resources.

Co-location, however, is not without costs. Existing companies that are considering participating in an EIP must take into account the costs of relocating to that particular site. Furthermore, the company will likely have to contribute to the capital costs of setting up an infrastructure to support the symbiotic activity. In addition to capital outlay, construction of this connectivity requires identifying and locking in specific tenants. The greatest enticement for joining the EIP is the competitive advantages offered through IS, so enlistment is difficult until a critical mass of willing candidates is assembled. Should a participating enterprise become defunct or simply choose to leave the EIP, the fragile business microcosm will suffer until a suitable replacement is found. Since the infrastructure does not generally lend itself to flexibility, it can be a formidable task to find a company that is willing to enter the community and who can fill the system's gap.

VEIPs avert many of the obstacles associated with conventional EIPs without detracting from the associated advantages. Most generally, a VEIP can be considered the evolutionary successor of material exchanges and conventional EIPs. Taking the best aspects of both constructs, VEIPs provide improved economic and environmental benefits without the constraints and limitations of the previous models.

Evidence supports the conclusion that the co-location aspect of conventional EIPs is advantageous. VEIPs have therefore been constructed to exploit the benefits associated with co-location while providing opportunity for more distant matching. Because some residual streams have inherent value that exceeds the cost of transportation (i.e. either the price density of the material is high or the scarcity of the material in the region is such that the price in the market supports the exchange), VEIPs can consider matches within any preselected radius. If the costs are justified, materials can be exchanged throughout a city, a region, or worldwide.

Where local exchanges may justify the capital costs of direct connectivity, exchanges at greater distances will require the use of current transportation modes. Although this added cost may reduce the likelihood of certain exchanges, the size of the VEIP community and its commensurate possibilities can dwarf the micro-economy of a conventional EIP. VEIPs also offer the advantage of modularity. After the critical mass of participants has been organized – a much easier challenge than the construction of a conventional EIP due to the larger area over which participants can be selected – additional firms and flow matches can be added one at a time. Other important benefits of VEIPs are: 1) allowing companies to disengage from the virtual community without economic penalty beyond lost opportunity, 2) providing greater varieties of possible exchanges, 3) lessening the reliance on individuals for system stability, and 4) not requiring high initial capital investment.

Evidence supports the conclusion that the co-location aspect of conventional EIPs is advantageous. VEIPs have therefore been constructed to exploit the benefits associated with co-location while providing opportunity for more distant matching.

THE VISION OF VIRTUAL EIPS

VEIPs can offer advantages to both private and public institutions. At the firm level, an existing facility can use the system to identify local companies which may benefit from an IS relationship. Matching input and residual streams, these firms find mutual economic benefit in an association that coincidentally reduces their burdens on natural resources and the environment. Companies also may find utility in the tool when siting a new facility. The user can provide the criteria for a search (e.g. "What regions of the country provide maximum opportunities for IS given my projected input and output streams?"), and the tool would output a list of regions and their associated potential matches. This output could then be exported to a Geographic Information System which would present the details graphically and assemble all other information relevant to the decision. Although many factors must be considered when locating a new business, this approach would assure that the differing opportunities for IS at each site would be included in the decision-making process.

City and regional development organizations can also benefit from a well-managed VEIP. By analyzing local businesses as an industrial system, public and private development organizations can identify specific industries that would benefit and would add benefit to the existing network. For example, a developer may use the tool to identify a sector gap and then proceed to set up an enterprise with private funds to exploit that opportunity. Similarly, an economic development organization could identify target industries to complement the existing installed base. Lastly, a city council might use the tool to identify IS possibilities for a specific company which it is trying to entice to relocate to the area. Either through direct development or through the promotion of external capital, organizations can employ VEIPs as an analytical and strategic tool for promoting economic opportunity.

In fifteen years, much of the world is likely to be connected through the World Wide Web or its progeny. Businesses throughout the world could subscribe to the MatchMaker! webpage and use its extensive regional and global databases to improve their resource efficiency. In fact, future versions of Netscape could be shipped with the site preinstalled as a bookmark.

As local VEIPs grow, they can continually update regional nodes which in turn communicate with the Local Area Node Collective Expert System (LANCES). This central processing unit could act as the global VEIP while providing the advantage of advanced expert systems integration. LANCES' "intelligent" elements learn with each new datum, providing the sub-networks with novel matches, improved hierarchies, and better predictive assessments. Inevitably, companies and governments will query local, regional, or global VEIPs in search of information essential to proper operational and strategic decision-making.

While typical waste exchange organizations can only help match generators and end users that are actively seeking one another, MatchMaker! can create proactive matches between firms which have not provided any data and may not even know of the existence of the MatchMaker! organization.

ENTER THE MATCHMAKER!

MatchMaker! is a relational database product, which we developed as a part of our group project. The program organizes and processes detailed materials flow information about specific facilities and generic industry types. Using input and output data for broadly defined material flows (e.g., solid, liquid, and gaseous items including steam and water), MatchMaker! is capable of generating reports that recommend potential symbiotic linkages between facilities.

MatchMaker! can suggest the kinds of pairings that are now orchestrated by waste exchange organizations. But while typical waste exchange organizations can only help match generators and end users that are actively seeking one another, MatchMaker! can create proactive matches between firms which have not provided any data and may not even know of the existence of the MatchMaker! organization. This sort of matching can help firms identify sites or geographic regions most amenable to waste linkages, and may provide critical insights for city or regional planners.

MatchMaker! is able to suggest potential matches between firms by drawing on generic flows organized by the standard industrial classification system (SIC) codes. If flow data are available for specific firms within the designated geographical search region, the program will identify such matches. If flow data are not available for firms within the region, the program will estimate probable flows based upon data gathered from firms in other regions belonging to the same SIC code, as well as generic profiles of flows for each SIC code.

By standardizing the names of all materials listed, MatchMaker! is able to automate the process of matching generators with end users. As all materials must be entered into the database according to a menu-driven taxonomy, there is no room for the inconsistent and sometimes ambiguous labeling of materials which plagues traditional waste exchange databases.

Using publicly available data sources (in our case, a $55 CDROM entitled ProCD Select Phone), MatchMaker! can extract the name, address, SIC code, and geo-referenced coordinates of most businesses in the United States. Because of the geo-referencing, searches for potential matches can be limited to a narrow geographic radius (appropriate for steam exchanges) or can be country-wide (appropriate for expensive electronic components). Eventually, MatchMaker!'s matching logic can be made to incorporate systems analysis optimization techniques.

The Development of MatchMaker!

Bechtel delivered to the group an Excel-based database of the Brownsville data. The spreadsheet structure was adequate for a trial of concept, which was proved in the Brownsville case. To move beyond the pilot phase a genuine relational database model was needed.

The relational database, if set up correctly, will substantially reduce the problem of inconsistent data. It also will allow the matching process to be done from within the database application. The application will be more stable and more easily maintained and the groundwork will be laid for the eventual migration to more powerful databases in the future.

First we designed the structure of the database, and then we created the database in Microsoft Access, a standard industry tool for the Windows PC. The new database features several design changes and greater functionality as compared to the original Excel model. These changes are described below.

New Features

The information about each firm or industry has been normalized – that is, broken up into separate tables. This new structure eliminates multiple entry of data, and makes for easier maintenance of the database.

Firms

Each firm has a master record, which contains such information as headquarters address, chief contact, and phone number.

Locations

For every firm, there can be number of locations, each of which has an SIC code, address, contact details and description.

Material Flows

The material flows were formerly contained in two tables, one for materials, and one for utilities. We could not find any specific reason for splitting the two flows and have therefore stored all material flows in one table. Thus, for each location, we can have any number of incoming and outgoing flows of materials or utilities (e.g. water, electricity, gas).

SIC Codes

Similarly, the database is now driven by Standard Industry Classification Codes. This system gives a consistent record of each location's true industry. Where the SIC code is obviously too broad, there is room to "zoom down" one more level and add discriminatory classification. This structure allows flows to be averaged on the basis of SIC code, generating standard generic flow data for each industry.

Material Codes

Similarly, the flows themselves required a classification system. This is crucial to the success of the database, because proper material flow matching is the goal of the program. Without a consistent material classification system, matching flows would be immensely difficult. The start of a predefined hierarchy has been incorporated into the database. Extension of the taxonomy given will be necessary as new information is added to the database.

Without a consistent material classification system, matching flows would be immensely difficult. The start of a predefined hierarchy has been incorporated into the database.

How it Fits Together

For each firm there are locations for which we have listed material flows. The locations are described by SIC codes, and the materials by our new material codes. Matching of flows and standardization of industry flows now becomes a reality.

How Information is Entered into MatchMaker!

When users open up the database, they are presented with the menu pictured below.

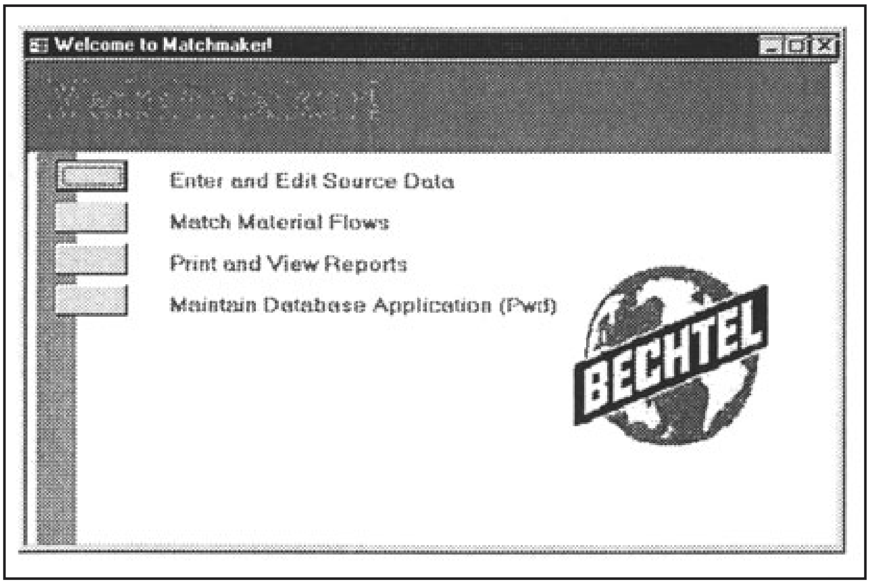

Figure 1 Database Front Page

The menu offers four options: editing data, printing reports, matching flows, and maintenance. Initially the add/edit data menu option will be the main one picked. A secondary menu (not shown) gives options for adding and editing data for Firms, SIC Codes, Material Flow Types, and any other data that need to be edited. Most of the effort in the early stages should be spent on the data input side. Hence most of the development work has been done in that area.

If users press the button next to Edit Firms, they will be presented with the combination Firms/Locations form below.

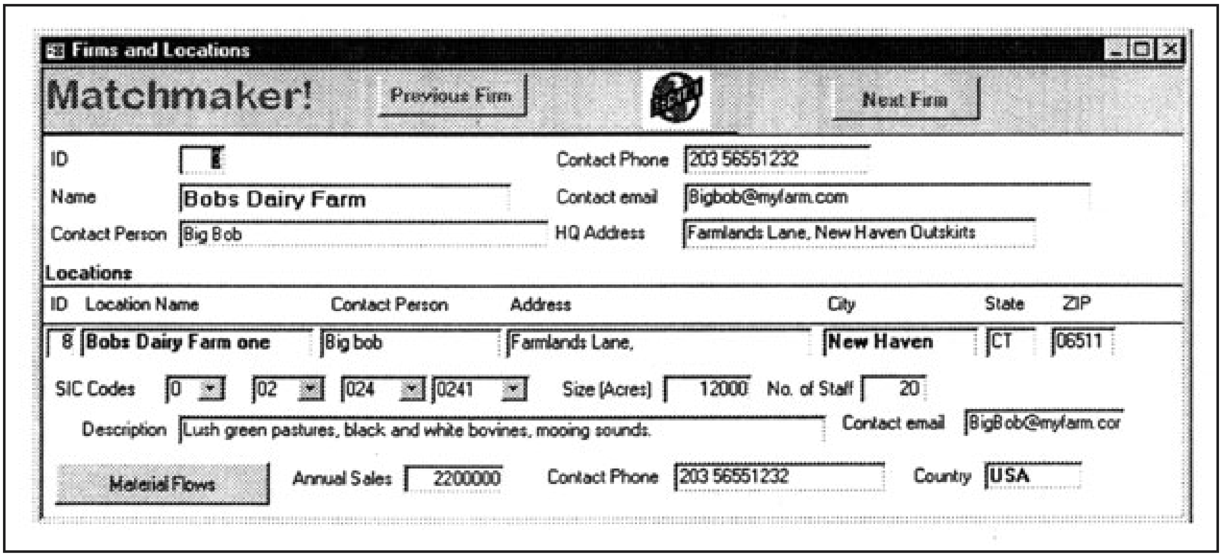

Figure 2 Firms/Locations Screen

The top of the form, with the white background, feeds data into the Firms table. The data here are very basic, reflecting a design philosophy to capture only the most relevant information and not to crowd out the users with data of lesser value.

The shaded (actually yellow) area shows one location. Additional locations can be added simply by moving the cursor down. The information captured here is a little more detailed and includes the four levels of SIC code, indicators of size (Staff and Area) and contact details. Longitude and latitude data are also stored but are not on the form as they are generally not known at the point of data entry. Commercial programs exist to convert address information into so-called geocodes.

When clicked, the SIC code fields show the complete list of relevant numeric and definitional information. The user can either type in the code or scroll down the list to the correct code. Additionally, typing in the first digits will scroll the list to the appropriate point.

When the Location data are complete, the user clicks on the "Material Flows" button. A new form pops up, as presented below.

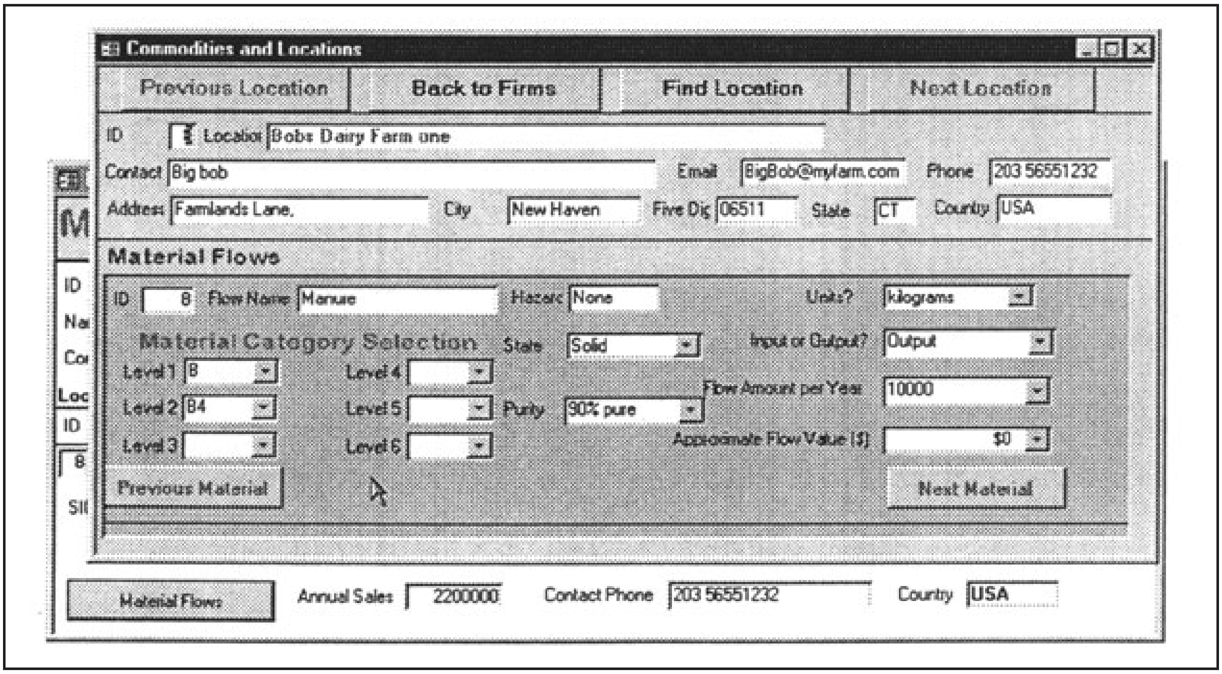

Figure 3 Material Flows Screen

For each location, there can be any number of flows of any type. The flows are added sequentially, and can be viewed by pressing the "Next Material" and "Previous Material" buttons. The top half of the form is data fed in from the previous form. The lower half of the form shows one material flow at a time. Basic information such as hazard code, flow volume and units, direction of flow (i.e., input or output), purity, and phase (state) is entered from drop down lists.

Material and Utility Taxonomy

The free-form field for "Flow Name" is not used for matching, which instead is done using the "Material Category Selection" level drop-down lists. Like the SIC code entry, the user can either select from the list, type in the value, or a combination of both.

These taxonomy lists are crucial for proper matching and thus are the keystones of the project. The function of the taxonomy is two-fold:

- provide a range specificity
- improve matching efficacy

An extensive hierarchy will provide the user with a continuum from general to highly specific. If one is searching for a well characterized item (e.g. aluminosilicate glass), then the search engine will find flows that match only that particular item (i.e., borosilicate and soda-lime glass will not be matched).

However, if any of a class of items will do (e.g., hydrocarbon solvents), then MatchMaker! will find a vast array of items which are listed under the category of hydrocarbon solvents (i.e., alcohols, acetates, hexanes, etc. will be found). Since the program graphically presents the hierarchy via drop menus, the user may decide that a more general selection is appropriate and choose not to use the lower levels. MatchMaker! will only find matches when reports matching the more generic criteria are generated. In this case, the possibility of successful matching is increased.

The fact that the taxonomy is pre-established also will increase the probability of successful matching. By selecting the search element from a list, near-misses due to misspelling, alternate naming schemes (e.g., butanol and butyl alcohol), misordering of phrases (e.g., "rubber, natural" as opposed to "natural rubber"), and formatting errors (e.g., extra spacing, misplaced punctuation) are prevented.

Associated with the advantages of a pre-established hierarchy are the problems of rigidity in a dynamic system. Depending on the use and contents of the database, the user may wish to expand the hierarchy to include new items or eliminate bulky, unused portions of the list. MatchMaker! has been designed with this function in mind. The hierarchy editing form is accessed from the add/edit menu form and will allow the user to perform modifications, additions, and deletions. All matches that follow will reflect the changes. The database stores the material code, not the material name in each flow, so if the material name is altered (e.g., the spelling of butanol) it will not affect the matchmaking ability.

Associated with the advantages of a pre-established hierarchy are the problems of rigidity in a dynamic system. Depending on the use and contents of the database, the user may wish to expand the hierarchy to include new items or eliminate bulky, unused portions of the list. MatchMaker! has been designed with this function in mind.

In order to properly design our hierarchy, we performed an extensive World Wide Web search of material exchange bulletin boards. What we found was a great disparity of taxonomies; the results offered us little help in selecting a standard. Instead, we selected a range of popular elements from numerous well-designed sites and then condensed and tailored them to suit our needs. Then, using a broader set of Web hierarchies, we flushed out the top two tiers to a modest but by no means exhaustive extent. In hopes of better demonstrating the function and structure of our model, we also performed a similar process on several elements in the Chemicals, WORP (waxes, oils, rubbers, plastics), and Metals/Sludges categories. The classification scheme as presented in Appendix B is incomplete but provides a useful prototype for hierarchic design.

Mass Regional Data

Data can be imported from available CD databases of U.S. industries such as "Select Phone" from ProCD. These databases contain information available in the Yellow pages for every region in the U.S. The Yellow pages classifications are used to generate one or more SIC Codes for each location. The locations are also geo-coded with longitude and latitude coordinates for each. Essentially, the CDs contain all of the data on the firm level and most of the data on the location level. Material flow data are not commercially available on CD.

Basic Matching

After these steps are taken, the MatchMaker! database can perform matching of material flows. The user has the choice of a number of reports. These reports vary by grouping and by material level. A company that was looking for a basic solvent of any type would run a "Flow by Material Type – Material Level 2" report. This report would show all of the input and output flows of that material. A company wanting to look at all of its specific matches would run "Match Flows by Company – Level 5" which would list all matches for that company's inputs and outputs.

The Level of Current Development

The fundamental structure of MatchMaker! is in place. Critically, this includes the underlying table design and associated queries. Forms for entry of Firm, Location, and Flow data have been created (as were shown above). The master matching queries and reports have been created for each method of grouping and one level. It is a relatively trivial matter to create new feeder queries to make reports that match materials on different levels.

A menu system is in place that can be progressively added to as the number of reports and forms expands. Simple forms for editing SIC Codes and Material Categories either exist or are easy to create. However, with data of this nature, it is simple to edit directly in the table.

Industry data were imported from "Select Phone" CD for the New Haven area, and are stored in a table. Additional data for larger or different areas are easy to import from this or similar products.

The Next Steps

Currently, there is only sample flow data in the MatchMaker! system. The Brownsville and Saudi data need to be imported – a task which we did not undertake since the specific material flows need to be collected and coded using the new material classification system.

Basic matches will be performed by running the appropriate reports. To limit the size of reports, a simple filter system needs to be incorporated so that users can show only those flows or companies in which they are interested. Because of the current paucity of data, this function is not yet necessary.

There are several cosmetic and "nice to have" features that take a long time to create but should eventually be added. These include a tree structure for adding the material and SIC codes, database security, database maintenance (such as repairing and compressing), and simple ad-hoc reporting and querying.

User Testing

User testing will certainly reveal areas that require improvement. Currently the database needs to be maintained by a person proficient with the Access product. Bechtel Research and Development may wish to extend and further develop the product.

MatchMaker! – The True Power

When enough data have been entered into the system, and a critical mass of standard SIC code-based material flows is available, then the true power of MatchMaker! will be revealed. In a relatively simple yet computationally intensive procedure, the SIC codes from the phone book CD-ROM are matched against the standard flow data. An overall flow schema of the area in question is generated and can be analyzed in several ways. First, the quantity of excess input and output flows from the entire region can be studied. For example, Connecticut would show a large inflow of oil and petroleum. If the database also showed an unusually large inflow of aluminum extrusions, or paper products, then perhaps there would be an opportunity.

The Flow Magnitude

The next level of analysis does not look at the difference of inflows and outflows, but rather the magnitude of flows. If there are noticeably large flows inside the region, then attention can be focused on determining whether they are being routed to the appropriate companies. For example, if there are a lot of wood input and output streams from local industries, we should investigate whether the wood is flowing entirely within the local economy or whether the net flows are actually imports and exports away from the area.

Proximity

At later stages, when more data are entered, proximity of data flows can be calculated by using an equation to calculate the distance between the two geo-coded points. This distance equation has been programmed into MatchMaker! already and is available to use for calculated fields on reports. This feature will allow reports to be generated that show matching flows by proximity to the company in question. Further refinement will produce a report that gives distance-weighted flows, which will lower the ranking of very small flows that happen to be next door compared to very large flows down the street. This feature is particularly relevant to common commodities such as steam, water, electricity, and sludge.

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Optimizing

Finally, the distance, flow, and material type data can all be exported into a systems optimizer application. This optimizer may be able to match flows across a larger area, such as New Haven County, and will optimize for the correct sequence and matching of flows. This step is an area where Bechtel can add a lot of value since they have developed proprietary optimization tools for use in other business sectors.

The choice of Microsoft Access as the database tool was made because this application allows for easy migration to more powerful databases. As an intermediate step, the tables of data can be migrated to a server database, such as Oracle, Sybase, or SQL Server. The front-end screens, forms, and reports would be retained. This simple migration is very easy to achieve. The next step is to change the existing queries to queries in native SQL, which can be directly passed through to the back end database. This improvement will significantly speed up searches and matches using very large amounts of data.

Finally, the forms and reports can be migrated to an industrial strength program such as Powerbuilder or Oracle Reports. This task requires a MIS project, with significantly more resources and scale than the MS Access solution. This final step, which should include web publishing, may not even be required as MS Access gains more robustness and high-end features with each new version.

MatchMaker! was developed in Access 97, the most recent version of MS Access available at the time of our project. Unfortunately this is not backwardly compatible with previous versions. However, if a 'developer kit' is purchased for a few hundred dollars, a "run time" version of Access 97 can be distributed with the MatchMaker! application. This would allow, for example, multiple data entry users using the runtime Access and one or two master users with the full product. Users of the runtime version would not be able to alter the structure of the MatchMaker! program, but could edit data, perform matches, and print reports as demonstrated before.

As the database grows, it would be tempting to copy it to allow different users to enter data at once. This is not ideal. If the users are all in the same office, they can log on to the database at the same time. However, if the users are separated by a greater distance, and are not networked, then splitting the database may be the only solution. In this case, for the data entry phase, an empty database would be provided to the satellite data entry group, and when the data entry was finished, the new records would simply be appended to the master database. Indexing concerns here require a unique reference "key" field in each table, so the satellite database would need to have tables which assign keys from a different start point.

However, the best medium term solution is to use the web publishing properties of Microsoft Access and place the database on an intranet, or the Internet. This would allow multiple updating of the same data tables at once. This new feature of Access has not been tested by the group, and would require some exploration before adoption.

When the SIC code data are sufficient to perform rough matches on a regional scale, the sheer volume of information presented will be overwhelming. One way to represent this array of information is on a map.

The Far Future

When the SIC code data are sufficient to perform rough matches on a regional scale, the sheer volume of information presented will be overwhelming. One way to represent this array of information is on a map. The matched flows could be shown by drawing lines from the start to finish points, with the thickness of the line representing flow rate, and the color or line style representing flow type. The tools to do this are commercially available. With some development, MatchMaker! would be able to export a flow line file to a mapping program such as "Maptitude" which can plot the flow lines onto a standard area map. The team has been experimenting with this technology with some success.

THE BIG QUESTION MARK: OWNERSHIP AND DATA COLLECTION

As it currently stands, MatchMaker! is a database frame without data. The tool works, but it is useless without input and output flow information for specific firms and SIC codes. Data collection will be an expensive endeavor, involving surveys, site visits, database mining, and literature review. While we have developed the basic framework of the MatchMaker! tool, we have not resolved the issue of ownership and funding for data collection.

We have envisioned three possible scenarios for the future control of MatchMaker!, each with advantages and disadvantages.

Scenario #1: Private Ownership

Under this scenario, a private organization such as Bechtel would maintain control of the database. Some of the initial data collection activities could be funded by client organizations interested in immediate local matchmaking similar to the Brownsville, Texas project. Additional data collection costs would be absorbed as research and development expenses toward a future product offering. As an inducement for early cooperation in providing input and output flow information, the owner of the database might offer free or discounted matchmaking services to participating firms in key industries.

From a utilitarian perspective, the primary drawback to this ownership scenario is that some potential clients would be unable to afford the prices charged for the matchmaking service.

In the short-run, we propose that MatchMaker! remain in the stewardship of the Yale School of Forestry and Environmental Studies. Student researchers should continue to develop the taxonomy of materials and collect flow data for firms in the greater New Haven metropolitan area.

Scenario #2: Public Ownership

Under this scenario, the federal government would own and operate the database. Firms could be required to submit input and output flow data, or alternatively, firms could be offered tax breaks and regulatory relief in exchange for their cooperation. While this scenario would provide broader access to the data than would the private ownership scenario, firms might be leery of participating and be hesitant to provide accurate flow data to a regulatory authority.

Scenario #3: Non-profit Ownership

Under this scenario, MatchMaker! would be controlled by a non-profit organization such as Yale University or the Environmental Defense Fund. Funding could come from a variety of sources including government grants, sliding scale subscriptions, or user fees based upon cost savings achieved.

In the short-run, we propose that MatchMaker! remain in the stewardship of the Yale School of Forestry and Environmental Studies. Student researchers should continue to develop the taxonomy of materials and collect flow data for firms in the greater New Haven metropolitan area.

Many critics question the economic viability of materials exchanges and pose the question: “Aren’t we talking about low-value commodities? If there were really significant cost savings opportunities, wouldn't businesses already have identified them?" In response, we offer the observation universally shared by the organizers of the waste exchanges with whom we spoke. Millions of dollars are saved each year by generators and users that find each other through waste exchange organizations. Some of the benefits are due to the decreased costs of industrial feedstocks, while other benefits stem from averted disposal expenditures. There appears to be plenty of low-lying fruit still out there. Adding sophistication, power, and detail to the matchmaking process would only increase cost savings.

APPENDIX A Sample web pages from on-line waste exchanges

Recycler's World - Information & Material Exchange Directory http://www.recycle.net/recycle/exch/...html

Recycler's World

[Go to Main Menu | Add Your Exchange]

Information & Material Exchange Directory

- Alabama Waste Materials Exchange (ALME)
- Alaska Materials Exchange
- Alberta Waste Materials Exchange
- Arizona Waste Exchange
- Arkansas Industrial Development Council
- BARTER Waste Exchange
- BBMS - La Bourse Bahillard des Matières Secondaires
- British Columbia Waste Materials Exchange
- By - Products & Waste Search Service
- C.R.U.M.B. - Crumb Rubber Universal Marketing Bureau
- CALMAX - California Material Exchange
- California Waste Exchange (CWE)
- Canadian Chemical Exchange
- Canadian Waste Materials Exchange
- Chicago Board of Trade
- Comex - Commodity Exchange Inc.
- ConnTAP Materials Exchange
- Cotton Commodity Exchanges
- Durham Region Waste Exchange
- Essex-Windsor Waste Exchange
- European Plastics Converters
- Florida Recycling Material System (FRMS)
- Gems, Rocks & Minerals Exchange
- Great Lakes Waste Exchange
- HIMEX-Hawaii Materials Exchange
- Hudson Valley Materials Exchange
- I.M.E.X. - Industrial Materials Exchange
- Indiana Materials Exchange
- Industrial Material Exchange Service
- Industrial Waste Information Exchange
- Inter-Continental Glass Exchange
- Inter-Continental Metal Exchange
- Inter-Continental Paper Exchange
- Inter-Continental Rubber Exchange
- Inter-Continental Tire Exchange
- Inter-Continental Wood Exchange
- Intercontinental Waste Exchange (IWE)

1 of 3 4/24/97

Recycler's World - Information & Material Exchange Directory http://www.recycle.net/recycle/exch/index.html

- International Fiberglass Exchange
- International Resource Recovery Network
- Kansas Materials Exchange
- Kentucky Industrial Materials Exchange
- Kobe Rubber Exchange
- Kuala Lumpur Commodity Exchange (KLCE)
- LME - London Metal Exchange
- La Bourse Quebecoise Des Materiers Secondaires
- Louisiana/Gulf Coast Waste Exchange
- MISSTAP
- Manitoba Waste Exchange (MBWE)
- Mat-Ex - Upstate New York Materials Exchange Program
- Michigan Resources Exchange Services
- Minnesota Technical Assistance Program
- Missouri Environmental Improvement Authority
- Money Lynx
- Montana Industrial Waste Exchange
- National Materials Exchange Network
- Nebraska Materials Exchange Program
- New Hampshire Waste Exchange (WasteCap)
- New Jersey Industrial Waste Information Exchange
- New Mexico Material Exchange
- Northeast Industrial Waste Exchange
- Ohio WasteNet - CEC Consultants
- Oklahoma Waste Exchange Program
- Ontario Waste Materials Exchange
- Pacific Materials Exchange
- Peel Regional Waste Exchange
- Portland Chemical Consortium
- Puerto Rico Waste Exchange
- Quebec Materials Waste Exchange (QMWE)
- Recycler's Exchange
- Resource Exchange Network for Eliminating Waste (RENEW)
- Rivanna Solid Waste Authority Exchange Program
- Rocky Mountain Materials Exchange
- SEMREX-Southeastern Minnesota Recyclers Exchange
- Saskatchewan Waste Materials Exchange (SWME)
- Singapore Commodity Exchange Ltd.
- South Carolina Waste Exchange
- Southeast Waste Exchange
- Southern Waste Info Exchange
- Southwest Virginia CommoditiesTrader
- Surplus Exchange
- TFE - Textile FiberSpace Exchange
- Tennessee Materials Exchange
- Tokyo Commodity Exchange (TCE)
- Transcontinental Materials Exchange
- Universal Plastics Exchange
- Vermont Business Materials Exchange
- WASTELINK - Div. of Tencon Inc.

Enviro Care Kruncher Corp.

BHS Bulk Handling Systems, Inc.

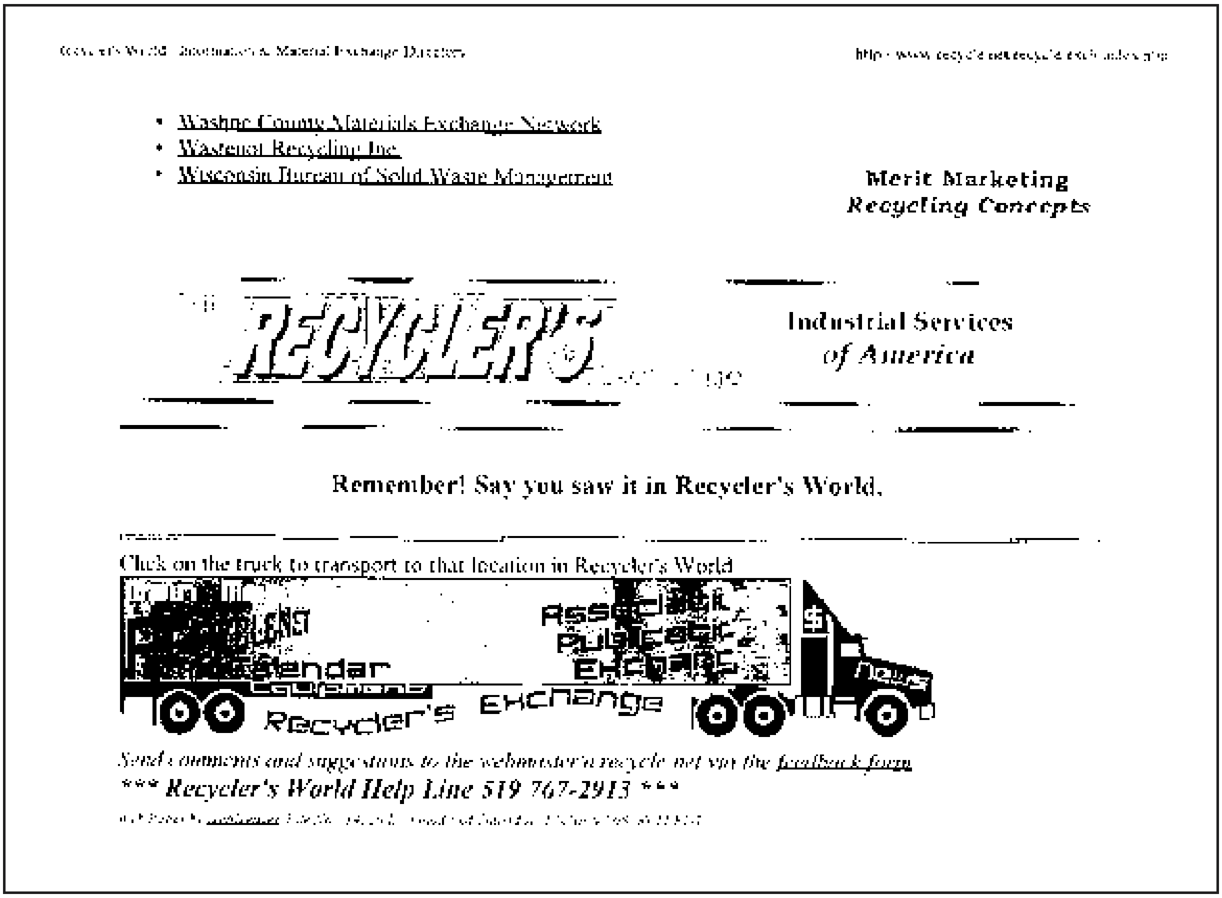
Garb-Oil & Power Corporation

BioResource

CHA Clough, Harbour & Associates LLP

E. Butterworth & Co., Inc.

2 of 3 4/24/97 7:36 PM



- Washoe County Materials Exchange Network
- Wastenot Recycling Inc.
- Wisconsin Bureau of Solid Waste Management
Merit Marketing
Recycling Concepts
Industrial Services of America
Remember! Say you saw it in Recycler's World.
Click on the truck to transport to that location in Recycler's World
Recycler's Exchange
*** Recycler's World Help Line 519 767-2913 ***

1997 March - April IMEX Catalog [illegible]

Local Hazardous Waste Management Program In King County

IMEX Catalog Table of Contents

Last Updated: April 16, 1997
Please e-mail IMEX directly at: imex@metrokc.gov

- *Search the King County home page, including IMEX*
- *On-line Listing Form Add your wanted or available materials to the IMEX catalog.*
- *Deadlines for IMEX Listings Due dates for getting your listings in specific catalog issues*
- *IMEX Report*
- *Business Waste Line*
- *How to Use This Catalog*
- *Laboratory Chemicals (Special Instructions)*
- *Telephone and address list of other material exchange & recycling networks*
- *Material exchange and recycling networks on the 'net*
- *Assistance for Your Waste Problems*

Available

*New Listings are marked with an asterisk (*), example: *A11092818*

01 Acids	02 Alkalis	03 Other Inorganic Chemicals	04 Solvents
05 Other Organic Chemicals	06 Oils/Waxes	07 Plastics/Rubber	08 Textiles/Leather
09 Wood/Paper	10 Metals/Metal Sludges	11 Miscellaneous	12 Laboratory Chemicals
13 Industrial/Other Equipment			

Wanted

1 of 2 4/24/97 7:50 PM

SWIX Materials Available http://www.webnsta.com/swix.ma.html

The Southern Waste Information Exchange (SWIX)

A Service of
Keep Florida Beautiful, Inc.

MATERIALS AVAILABLE

How to respond to or place a Material Available listing

* = New Listing

I. Acids

Code Number	Material	Quantity/Year	Location
SW:A01-0510	Chromic Acid	3,300 gallons, one time	AL
SW:A01-0512	Hydrochloric Acid	12,000,000 gallons	TX
SW:A01-0598	Hydrochloric Acid	16,000,000 gallons	FL
SW:A01-0612	Hydrochloric Acid	400,000 pounds/year	FL
SW:A01-0613	Solidified Pyrophosphoric Acid	4,400 pounds	GA

II. Alkalis

Code Number	Material	Quantity/Year	Location
SW:A02-0611	Calcium Carbonate Lime Mud	13,000 tons/year	GA
SW:A02-0601	HCE Black Liquor	100,000 pounds/day	FL
SW:A02-0587	Hydrated Lime	3 tons per week	FL
SW:A02-0624*	Hydrogen Peroxide	55 gallons	FL
SW:A02-0618	Lime Mud	270,000 cubic yards	FL
SW:A02-0620	Lime Solid	375,000 tons	FL

III. Other Inorganic Chemicals

Code Number	Material	Quantity/Year	Location
SW:A03-0530	Amorphous Silica	High tonnage	FL
SW:A03-0614	Iron Sulfate	50,000 pounds/week	MS

1 of 4 4/24/97 7:47 PM

1997 March - April IMEX Catalog http://www.metrokc.gov/[illegible].htm

*New Listings are marked with an asterisk (*), example: *W11092818*

01 Acids	02 Alkalis	03 Other Inorganic Chemicals	04 Solvents
05 Other Organic Chemicals	06 Oils/Waxes	07 Plastics/Rubber	08 Textiles/Leather
09 Wood/Paper	10 Metals/Metal Sludges	11 Miscellaneous	12 Laboratory Chemicals
13 Industrial/Other Equipment			

Volume 9 Issue No. 2
Return to the CESQG Home Page

Keeper of the CESQG Network Pages
Local Hazardous Waste Management Program in King County
King County Department of Natural Resources (formerly Metro)
Hazardous Waste Unit
130 Nickerson St., Suite 100
Seattle, WA 98109-1658
email: kcecsqg@metrokc.gov
Phone: (206)689-3051

Established : 1/13/96
Last update : 4/17/97

IV. Solvents

Code Number	Material	Quantity/Year	Location
No listings at this time			

V. Other Organic Chemicals

Code Number	Material	Quantity/Year	Location
SW:A05-0617	Diethylene Triamine (DETA)	15,000 pounds	AL
SW:A05-0599	Ethylene Glycol/Antifreeze/Coolant	NA	UT
SW:A05-0545	Glycerine	3,000 gallons	FL
SW:A05-0445	Heat Transfer Fluids - Including Glycols	Various amounts	AR

VI. Oils and Waxes

Code Number	Material	Quantity/Year	Location
SW:A06-0625*	Used Oil/Fuel Mixed	12,000 gallons	FL
SW:A06-0517	Waste Motor Oil	2,750 gallons	TN

VII. Plastics and Rubber

Code Number	Material	Quantity/Year	Location
SW:A07-0628*	Amoco TA/22 Resin	84,000,000 pounds	SC
SW:A07-0544	Crumb Rubber	6,000,000 pounds	FL
SW:A07-0542	Microfilm Tape	Various Amounts	FL
SW:A07-0560	Nylon/Rubber Tires	Varies	FL
SW:A07-0549	Polyvinylchloride Foam	120,000 pounds	TN
SW:A07-0623*	PP & PE Blend	480,000 pounds	MO
SW:A07-0543	Processed Tire Buffings	2,016,000 pounds	FL
SW:A07-0602	TDI Foam	50,000 pounds	FL
SW:A07-0514	Teflon	100,000 pounds	AR
SW:A07-0483	Vinyl Nitrile Foam Scrap	6 truckloads per month	FL
SW:A07-0621*	Waste Ink Buckets - HDPE #2	78,000 pounds	KY

APPENDIX B Prototype materials taxonomy

CATEGORY LEVEL A: CHEMICALS

A1 Acids
- A1A inorganic
  - A1A1 hydrogen sulfide
  - A1A2 hydrogen cyanide
  - A1A3 hydrofluoric acid
  - A1A4 hydrochloric acid
- A1B organic

A2 Alkali
- A2A inorganic
  - A2A1 ammonia
  - A2A2 sodium hydroxide
- A2B organic

A3 Solvents
- A3A inorganic
- A3B organic
  - A3B1 hydrocarbons
    - A3B1A 1,2-epoxybutane
    - A3B1B 1,2-butadiene
    - A3B1C 2,2,4-trimethylpentane
    - A3B1D acetalhehyde
    - A3B1E acetates
      - A3B1E1 n-butyl acetates
      - A3B1E2 methyl ether acetate
      - A3B1E3 isopropyl acetate
      - A3B1E4 ethylene glycol diacetate
    - A3B1F acetone
    - A3B1G acetophenone
    - A3B1H alcohols
      - A3B1H1 isopropranol (isopropyl alcohol)
      - A3B1H2 methanol (methyl alcohol)
      - A3B1H3 n-butanol (n-butyl alcohol)
      - A3B1H4 propanol (propyl alcohol)
      - A3B1H5 octanol (octyl alcohol)
      - A3B1H6 methyl oxitol
    - A3B1J benzene
    - A3B1K biphenyl
    - A3B1L dibenzofuran
    - A3B1M ethyl glycol
    - A3B1N ethylbenzene
    - A3B1P ethylene glycol monomethyl ether
    - A3B1Q hexanes
    - A3B1R hexylene glycol
    - A3B1S methyl ethyl ketone (MEK)
    - A3B1T methyl-t-butyl ether
    - A3B1U napthalene
    - A3B1V phthalates
      - A3B1V1 di-2-ethyl-,hexylphthalate
      - A3B1V2 dioctyl phthalate
      - A3B1V3 bis(2-ethylhexyl) phthalate
    - A3B1W propylene glycol monomethyl ether
    - A3B1X propylene oxide
    - A3B1Y xylenes

A3B2 N-containing compounds
- A3B2A 2,4-dinitrotoluene
- A3B2B 2-nitropropane
- A3B2C 4-nitrobiphenyl
- A3B2D 4-nitrophenol
- A3B2E acrylamide
- A3B2F acrylnitrile
- A3B2G diazomethane
- A3B2H hydrazine (35%)
- A3B2J hydroxylamine hydrochloride
- A3B2K nitrobenzene
- A3B2L nitromethane
- A3B2M triethylamine

A3B3 P-containing compounds
- A3B3A phosgene
- A3B3B phosphine

A3B4 mixed compounds
- A3B4A bromoform
- A3B4B bromomethane (methyl bromide)
- A3B4C carbon tretrachloride
- A3B4D chlorobenzene
- A3B4E chloroethane
- A3B4F chloroform
- A3B4G chloromethane (methyl chloride)
- A3B4H 1,4-dichlorobenzene
- A3B4J freons
  - A3B4J1 freon-113
- A3B4K halons
  - A3B4K1 halon-1301
  - A3B4K2 halon-1211
- A3B4L perchloroethylene
- A3B4M perchloroethylene
- A3B4N trichlorobenzene
- A3B4P trichloroethane
- A3B4Q trichloroethylene
- A3B4R vinyl bromide
- A3B4S vinyl chloride
- A3B4T 1,1,2,2-tetrachloroethane
- A3B4U 2,4,5-trichlorophenol

A3B5 halogen-containing compounds
- A3B5A 2-acetylaminofluorine

A4 Salts

A4A inorganic
- A4A1 calcium hypochlorite
- A4A2 calcium oxide
- A4A3 magnesium oxide
- A4A4 potassium dichromate
- A4A5 potassium ferricyanide
- A4A6 sodium chloride

A4B organic
- A4B1 sodium acetate, anhydrous
- A4B2 sodium proprionate

A5 Ceramics
- A5A oxide
  - A5A1 yttria
  - A5A2 magnesia
  - A5A3 alumina
- A5B non-oxide
  - A5B1 boron carbide
  - A5B2 silicon nitride
  - A5B3 silicon carbide
- A5C silicate
  - A5C1 glass
    - A5C1A silica
    - A5C1B soda-lime
    - A5C1C borosilicate
    - A5C1D aluminosilicate
    - A5C1E leaded
  - A5C2 cement
  - A5C3 pottery and structural clay

A6 Non-Solid Petroleum Distillates
- A6A methane
- A6B ethane
- A6C propane
- A6D butane
- A6E naptha
- A6F kerosene
- A6G gas oil

A7 He, H2, X2 gases
- A7A chlorine
- A7B cyanide
- A7C fluorine
- A7D helium
- A7E hydrogen

A8 Inorganic Solids
- A8A carbon
  - A8A1 carbon, black
  - A8A2 carbon, charcoal
- A8B silica (silicon dioxide)

CATEGORY LEVEL B: AG./FOOD

B1 Compost

B2 Fish Wastes

B3 Fruit and Vegetable Wastes

B4 Manure

B5 Mulch

B6 Rendering and Protein Wastes

B7 Processed/Packaged Food Wastes

B8 Fly Ash

CATEGORY LEVEL C: WORP

C1 Wax
- C1A petrolatum

C2 Oil
- C2A lube oil

C3 Rubber
- C3A natural
- C3B synthetic
  - C3B1 butyl
  - C3B2 EPDM
  - C3B3 fluorocarbon
  - C3B4 latex
  - C3B5 neoprene
  - C3B6 nitrile
  - C3B7 polybutadiene
  - C3B8 silicone
  - C3B9 SBR

C4 Plastic
- C4A ABS
- C4B EP
- C4C nylon (polyamide)
- C4D PBT
- C4E PET
- C4F polycarbonate
- C4G polyethylene
- C4H polypropylene
- C4I PS
- C4J PVC
- C4K SAN
- C4L SI
- C4M teflon
- C4N vinyl nitrile
- C4P unidentified plastic scraps
  - C4P1 film scrap
  - C4P2 shrink wrap
  - C4P3 stretch wrap
  - C4P4 packaging peanuts
  - C4P5 plastic bags

CATEGORY LEVEL D: TEXTILES/LEATHER

D1 Cotton

D2 Wool

D3 Burlap, Jute, Sisal

D4 Polyurethane Foam

D5 Polyester Fibers

D6 Nylon Fibers

D7 Other Syntheic Fibers

D8 Rags and Wipers

D9 Leather

CATEGORY LEVEL E: WOOD/PAPER

E1 Pallet Reels and Crates

E2 Lumber (Virgin or Reusable)

E3 Waste Wood

E4 Wood Chips, Shavings, and Sawdust

E5 Paper (Virgin or Reusable)

E6 Loose Paper Waste

E7 Baled Paper Waste

E8 Paperboard

E9 Corrugated Cardboard

CATEGORY LEVEL F: METALS/SLUDGE

F1 Iron and Steel
- F1A used/reusable iron
- F1B scrap iron
- F1C ship breaking and railroad iron
- F1D used/reusable steel
- F1E scrap steel

F2 Non-Ferrous Metals
- F2A aluminum
- F2B brass and bronze
- F2C copper
- F2D lead
- F2E magnesium
- F2F tin
- F2G zinc
- F2H other non-ferrous metals

F3 Exotic Metals
- F3A cobalt
- F3B nickel
- F3C mercury
- F3D titanium
- F3E tungsten
- F3F other exotic metals

F4 Precious Metals
- F4A gold
- F4B palladium
- F4C platinum
- F4E silver
- F4F other precious metals

APPENDIX C Sample MatchMaker! reports.

MATCH FLOWS BY FIRM AND LOCATION

Bobs Dairy Farm

Matches For Location: Bobs Dairy Farm one New Haven

Output

Matches for Material: Manure

Quantity of Flow: 10000 kilograms **Purity:** 03

Internal Name Manure

Firm Name Yale University **Location** Yale University Dining Services Food and other products recycler

Contact Person Bill Taco

Flow Type: Input **Flow Name:** "Food Stuffs" **Quantity:** 1000000 kilograms

Form: Solid **Purity:** 100% Pure

Firm Name Hamden Golf Course **Location** Hamden golf Course Public golf course

Contact Person Arnie Palmer

Flow Type: Input **Flow Name:** Manure **Quantity:** 1000 kilograms

Form: Solid **Purity:** 95% pure

Bobs Dairy Farm

Matches For Location: Bobs Dairy Farm one New Haven

Firm Name United Illuminating **Location** UI Fuel Cell Place Pilot project - takes manure, makes methane, runs fuel cells. Innovative but smelly.

Contact Person Alva Edison

Flow Type: Input **Flow Name:** Manure **Quantity:** 1000 kilograms

Form: Solid **Purity:** 95% pure

Brick Manufacturer

Matches For Location: **Potential Brick Manufacturer** New Haven

Output

Matches for Material: Construction Material
Quantity of Flow: 10000 kilograms **Purity:** 03
Internal Name Brick bits

Firm Name Dodgy Brothers Construct **Location** Dodgy Brothers Construction Engineers and builders to the public.
Contact Person Dodgy Dan

Flow Type: Input **Flow Name:** Brick pieces **Quantity:** 10000 kilograms
Form: Solid **Purity:** Contaminated

Input

Matches for Material: Fly Ash
Quantity of Flow: 10000 kilograms **Purity:** 0[illegible]
Internal Name fly ash

Brick Manufacturer

Matches For Location: **Potential Brick Manufacturer** New Haven

Firm Name Yale University **Location** Yale University Power Power Generation
Contact Person Bob Wildman

Flow Type: Output **Flow Name:** Fly ash **Quantity:** 10000 kilograms
Form: Solid **Purity:** 95% pure

Firm Name Connecticut Light and Po **Location** New Haven Coal Power Power generation
Contact Person

Flow Type: Output **Flow Name:** Flyash **Quantity:** 1038800 metric tonnes
Form: Solid **Purity:** Contaminated

Connecticut Light and Power

Matches For Location: **New Haven Coal Power** New Haven

Output

Matches for Material: Fly Ash

Quantity of Flow: 1000000 metric to **Purity:** 04

Internal Name Flyash

Firm Name Brick Manufacturer **Location** Potential Brick Manufacturer Typical Brick Manufacturer. Average of 5 sample companies

Contact Person

Flow Type: Input **Flow Name:** fly ash **Quantity:** 10000 kilograms

Form: Solid **Purity:** 90% pure

APPENDIX C, continued Sample MatchMaker! reports.

Output

Matches for Material: Construction Material
Quantity of Flow: 10000 kilograms Purity: 03
Internal Name Brick bits

[illegible]
Location: Potential Brick Manufacturer New Haven

Firm Name Dodgy Brothers Constru Location Dodgy Brothers Construction Engineers and builders to the public
Contact Person Dodgy Dan

Flow Type: Input Flow Name: Brick pieces Quantity: 10000 kilograms
Form: Solid Purity: Contaminated

Dodgy Brothers Construction
Location: Dodgy Brothers Construction New Haven

Firm Name Brick Manufacturer Location Potential Brick Manufacturer Typical Brick Manufacturer Average of 5 sample companies
Contact Person

Flow Type: Output Flow Name: Brick bits Quantity: 10000 kilograms
Form: Solid Purity: 90% pure

Output

Matches for Material: Fly Ash
Quantity of Flow: 10000 kilograms Purity: 02
Internal Name Fly ash

Yale University
Location: Yale University Power New Haven

Firm Name Brick Manufacturer Location Potential Brick Manufacturer Typical Brick Manufacturer Average of 5 sample companies
Contact Person

Flow Type: Input Flow Name: fly ash Quantity: 10000 kilograms
Form: Solid Purity: 90% pure

Input

Matches for Material: Fly Ash

Quantity of Flow: 10000 kilograms **Purity:** 03

Internal Name fly ash

Brick Manufacturer
Location: Potential Brick Manufacturer New Haven

Firm Name Yale University **Location** Yale University Power Power Generation

Contact Person Bob Wildman

Flow Type: Output **Flow Name:** Fly ash **Quantity:** 10000 kilograms

Form: Solid **Purity:** 95% pure

Firm Name Connecticut Light and Po **Location** New Haven Coal Power Power generation

Contact Person

Flow Type: Output **Flow Name:** Flyash **Quantity:** 1000000 metric tonnes

Form: Solid **Purity:** Contaminated

Connecticut Light and Power
Location: New Haven Coal Power New Haven

Firm Name Brick Manufacturer **Location** Potential Brick Manufacturer Typical Brick Manufacturer: Average of 5 sample companies

Contact Person

Flow Type: Input **Flow Name:** fly ash **Quantity:** 10000 kilograms

Form: Solid **Purity:** 90% pure

Matchmaker: New Haven

Clark Special Economic Zone: Finding Linkages in an Existing Industrial Estate 1998

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ABSTRACT
The Clark Special Economic Zone (CSEZ) is one of the most vibrant economic centers in the Philippines. A former U.S. air base, the CSEZ has been transformed into a successful industrial park with some 200 companies and is the catalyst for regional development. This paper was developed by a team of four students from the Yale School of Forestry & Environmental Studies in the hopes that it may assist the Clark Development Corporation (CDC) to integrate concepts and tools of industrial ecology into its development plans for the CSEZ, toward the larger goal of creating a sustainable eco-industrial park (EIP). It must be clarified from the outset that we performed this analysis as a class exercise done in consultation with CSEZ, but there was no attempt to achieve the commitment or support of the Zone's leadership.

CONVERTING CSEZ INTO AN ECO-INDUSTRIAL PARK

In an effort to facilitate the conversion of CSEZ from an industrial park to an EIP, this paper provides guidance on the most obvious potential symbiotic relationships on site. Identified are materials and energy exchange options, and technical guidance for the same, among six of the main industries on site, including electronics, tobacco, plastics, energy production, tires, and textiles. To a lesser degree the airport, the golf course, landscaping, housing, and the tourist and service facilities are included in this model. These will be focused on more closely in defining long-term goals for an EIP conversion in the conclusion of this paper.

There are a number of eco-industrial park examples upon which many of these recommendations are based, including the Port of Cape Charles (the U.S.), Brownsville Matamoros (the U.S. and Mexico), Chemical Valley (Canada), and Kalundborg (Denmark).

MAKING THE CONNECTIONS

At present, the CSEZ is home to a number of industries that operate essentially independently from one another. In this exercise, we weave an intricate web of interdependent relationships among these various actors. This paper outlines recommendations for heat and energy flows, addresses water conservation and cycling, discusses oil and solvent recovery and reuse programs, and looks at material flows of compost and scrap tires.

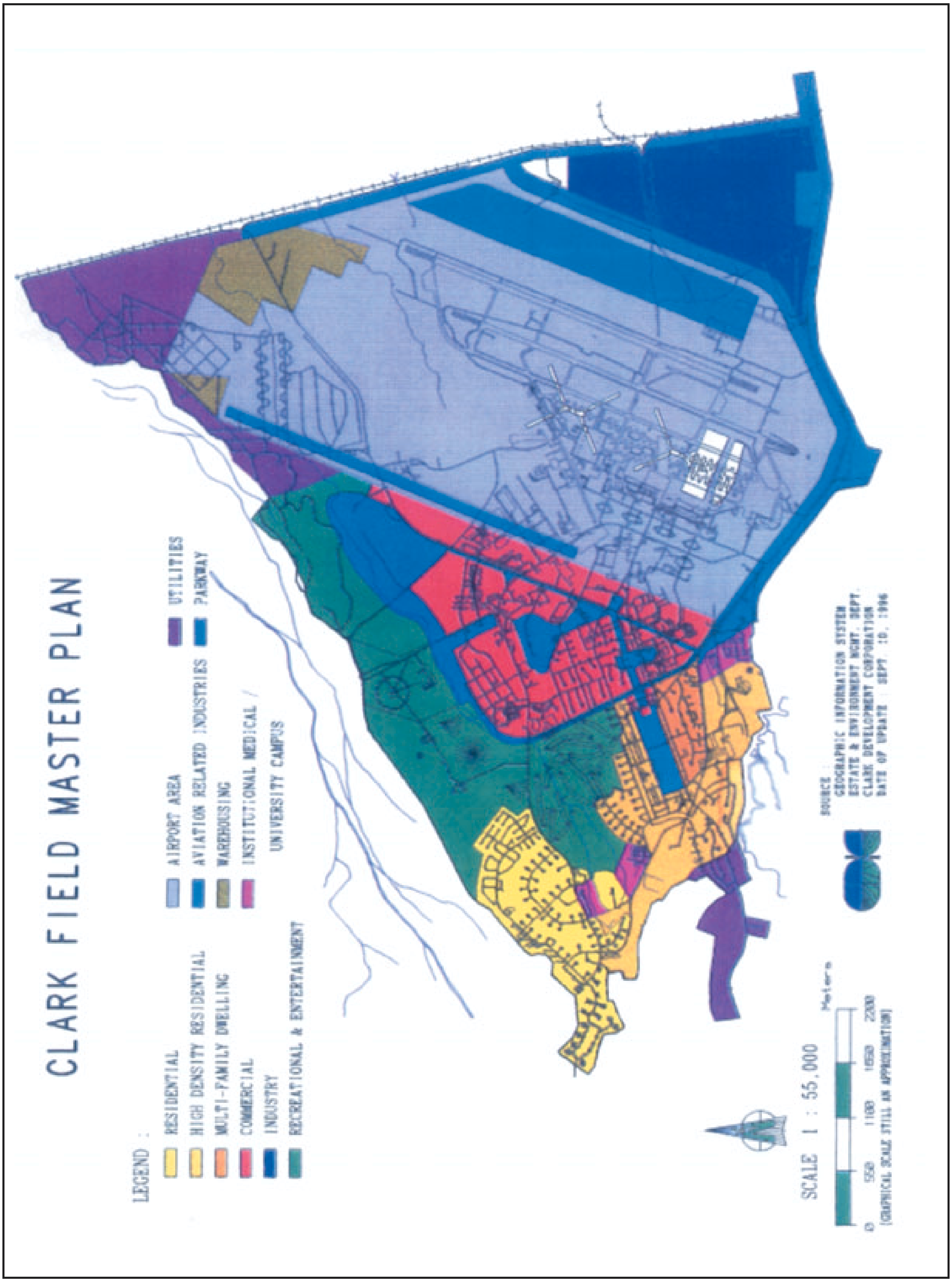

Figure 1 Clark Field Master Plan

HEAT AND ENERGY FLOWS

Using industrial symbiosis at Kalundborg as a model, we have placed the planned 250 MW oil-fired power plant at the heart of the CSEZ. In designing an eco-industrial park, a 50% reduction in energy consumption is feasible with utilization of waste steam heat from the power plant (Lowe *et al.* 1995). However, due to the tropical climate of the Philippines, use of the waste steam energy for home, office, and factory heating is not necessary. Therefore, waste steam energy utilization must be limited to industrial processes that require a heating or drying step. Before detailing the flows of waste steam heat at the CSEZ, we will evaluate the benefits of co-generation and estimate the possible steam quantities and temperatures.

Benefits of Combined Heat and Power Production

By combining heat and power production, fuel conversion efficiencies from 70-80% can be achieved in standard power plants. These efficiencies are much greater than the U.S. national averages of roughly 30% in utility electric production, and 39-66% in heating production (Hennagir 1998). Internationally, combined heat and power co-generation technology is widely recognized as one of the most efficient ways to meet electricity and heat needs. Approximately seven percent of Europe's electricity is produced by co-generation, although the amount varies widely from country to country, peaking at over 30% in the Netherlands, Denmark, and Finland (*Petroleum Times* 1996). In addition to increased efficiency of fuel conversion, employing co-generation schemes can reduce thermal pollution and cooling water usage (Gertler and Ehrenfeld 1997).

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Estimated Outputs of Useable Steam

An analysis of existing combined heat and power (CHP) facilities gives a first-order approximation of the available steam for industrial activities in the CSEZ. Many CHP facilities are independent power producers within an individual industrial facility, with generally smaller electricity outputs than power plants that are a part of a regional grid. For instance, in Great Britain, where CHP is common, one papermaker's CHP facility can produce 80 MW of electricity and over 620,000 pounds of steam per hour for local industrial and municipal uses. The steam produced is enough to heat approximately 25,000 homes during winter (*Director* 1997).

Oil refineries have benefited from CHP facilities, using both the electricity and steam energy in the refining processes. For instance, an 84 MW power project at Amoco Canada Petroleum Co.'s Primrose heavy-oil operation in Northeast Alberta can produce about a million pounds per hour of high-pressure steam (Hennagir 1998). The Anaes Power Station at Kalundborg generates 1500 MW of electricity and produces over 25 million pounds of usable steam per hour (Lowe *et al.* 1995). This steam is utilized by the Statoil Refinery, providing 40% of its steam requirements, and by the pharmaceutical company Novo Nordisk. Novo Nordisk has replaced its in-house boiler system with the cogenerated steam source, relying solely on the power plant for its steam. The two-mile steam pipeline built for the waste exchange between the Anaes power plant and Novo Nordisk paid for itself within two years (Ehrenfeld and Gertler 1997).

A U.S. natural gas-fired co-generation project, developed by Trigen Energy Corp., PECO Energy Co., and NRG Generating in Philadelphia, is similar in output and steam transfer system design to the proposed power plant at the CSEZ. The Trigen plant produces 150 MW of electricity and 1.5 million pounds per hour of steam, and has a projected fuel conversion efficiency of 70%. Trigen's pipe system loses about 12% of its energy during transmission, and Trigen's most distant customer is three miles away (Hennagir 1998). In a traditional steam turbine power system, the combustion chamber generates high-pressure steam at temperatures around 550°C (approximately 1,000°F). After the steam turns the turbine, the steam temperature drops to 125-175°C (250-350°F) (Ellis 1997). Extrapolating from the Trigen example of 12% losses, it is theoretically possible to retain temperatures in the 90-150°C (200-300°F) range for some considerable distance.

From the evidence above, we could reasonably expect to have over 2 million pounds per hour of usable steam generated by the 250 MW power plant, for use in any interested industrial facility located within a 3 mile radius of the power plant. As shown on the map in Figure 1, this covers most of the CSEZ's industrial areas. At this distance, steam temperatures in the 90-150°C (200-300°F) range can be maintained. These temperatures are suitable for most low-temperature industrial applications such as heating and drying.

A simple transfer of waste steam from the power plant [to the two tobacco processing facilities] would provide large volumes of sufficiently hot steam to run forced-airdrying machines. This would result in a necessary savings in energy consumption by replacing furnaces and/or electric powered heat sources.

Materials Flows of Steamheat Energy

Figure 2 shows a hypothetical flow diagram linking the 250 MW power plant to the following four major industrial applications: tobacco flue curing and drying, greenhouse heating, chemical processing of cosmetics, and rubber vulcanization in tire manufacture. These industries were chosen due to their use of heat as an integral part of the production process.

One of the simplest transfers of steam heat would be from the power plant to the two tobacco processing facilities currently in the CSEZ, Amity Manufacturing & Marketing Corporation and Nise Tobacco International Corporation. These two facilities have flue curing and redrying processes that require heat inputs. A simple transfer of waste steam from the power plant would provide large volumes of sufficiently hot steam to run forced-airdrying machines. This would result in a necessary savings in energy consumption by replacing furnaces and/or electric powered heat sources. This process would most likely require temperatures in the 50-150°C (125-300°F) range, which should be available from the power plant.

The Clark Development Corporation plans to build greenhouses to grow landscaping plants for the eco-industrial park community and the golf courses (Magat 1998). Although in a tropical climate, the greenhouses would benefit

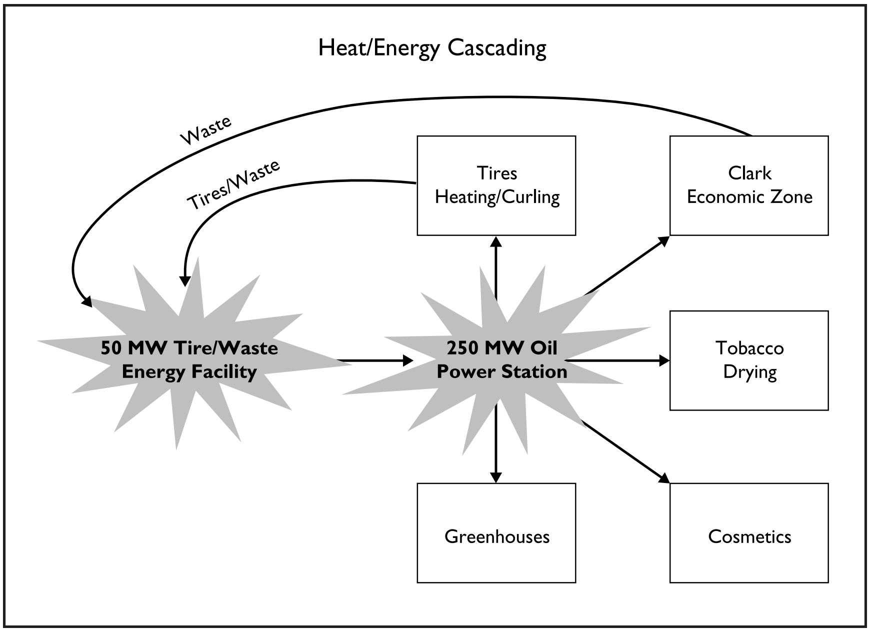

Figure 2 Heat/Energy Cascading

from supplemental heat energy to ensure constant temperatures in the 25-100°C (80-212°F) range and could easily be implemented, considering the small quantities of steam required.

The CSEZ has one chemical manufacturing company, Wei Mei Li Chemical Manufacturing Company, which may have a use for waste steam heat in similar applications as Novo Nordisk in Kalundborg. Wei Mei Li manufactures cosmetics and consumer plastics for export, which may require inputs of heat energy in various processing steps. For instance, heat inputs assist the emulsification of water and petroleum based phases to create certain cosmetic products. Temperatures in the 50-100°C (122-212°F) are reasonable for this process (Kasprzak 1996), and could be easily supplied by waste steam energy from the power plant.

A final possible materials flow of steam and heat energy involves transfer of steam heat to Yokohama Tire Corporation, to be used in the vulcanization and curing processes of rubber for tire manufacture, which requires a series of heating and cooling steps. In the rubber vulcanization process, pellets or granules of input polymers are mixed and heated in a hopper before being forced through a screw or ram type extruder (Norman 1996). The hot feed extruder is fed material at approximately 120°C (250°F) (Tuccio 1994), which would require external heat inputs that could be provided by the waste steam energy. After extrusion, the rubber is heated in a curing step to encourage polymerization, which is another possible utilization of waste steam heat. Curing requires temperatures in the 120-160°C (250-320°F) range to achieve the desired degrees of polymerization (Ignatz-Hoover *et al.* 1996). The temperatures required for vulcanization are near the maximum estimated temperature ranges of the waste steam generated by the power plant. The overall feasibility of this proposed link will require further investigation.

Short-Term Power Plant Options

Co-generation does not simply imply using waste energy for heat in industrial processes. Combined-cycle power plants can use the principle internally by combining a gas-fired turbine generator with a traditional steam turbine generator to achieve heightened efficiencies. The first-stage gas turbine creates electrical energy on its own and generates significant quantities of waste heat that can be transferred to water to create high-pressure, high-temperature steam. This high-pressure and high-temperature steam can then generate electricity in a traditional steam generator. Finally, the waste steam from this process can be fed into the co-generation waste stream flows described above, to perform work in the industrial applications. This would increase the overall combined heat and power efficiency beyond the 70-80% expected in a simple combined heat and power model. This recommendation would require adjustment of the currently planned power station, possibly adding a first-stage gas turbine generator to the planned steam generator.

In addition to the 250 MW power plant, there is an outdated 50 MW power plant at the CSEZ, which is a relic of the Clark Air Force Base. This environmental liability was partially damaged by the eruption of Mt. Pinatubo in 1992 and has fallen into disrepair. Instead of demolition and costly clean-up, it may be possible to retro-fit this "brownfield" site to once again be a power generator, potentially fueled by tire and municipal waste. There are significant quantities of scrap tires and general household waste available to fuel a waste-to-energy power plant. Admittedly, this is a transfer of a solid waste emission to gaseous ($C0_2$) and solid waste emissions (scrubber sludge and furnace ash). However, the reduced impact on the island nation's limited land area and the savings from disposal costs could be a net environmental benefit.

In addition to the 250 MW power plant, there is an outdated 50 MW power plant at the CSEZ, which is a relic of the Clark Air Force Base. Instead of demolition and costly clean-up, it may be possible to retro-fit this "brownfield" site to once again be a power generator, potentially fueled by tire and municipal waste.

Longer Term Conservation and Renewable Energy

The use of co-generation systems is a first step in increasing overall energy efficiency in the CSEZ. However, there are many other forms of energy conservation that require either capital investment on the part of individual companies, and/or changes in attitude through education. Conservation can be as simple as "smart" lighting which turns off when the space is not in use, low energy light bulbs, or increased insulation to retain heat or cold (from air conditioning systems). Or, conservation can be complex with highly technical energy cascading schemes to attempt to capture and use every last joule of energy created in the industrial system (Kashiwa 1996).

Due to the close proximity of the CSEZ to the Mt. Pinatubo volcanic complex, an investigation of alternative energy sources to reduce reliance on fossil fuels should focus on the utilization of geothermal energy. Geothermal power plants extract heat from water or steam that naturally circulates through underground rocks in volcanically active areas. In California, Nevada, Utah, and Hawaii, 70 hydrothermal plants each have an electric generating capacity of some 2,800 MW. Geothermal energy currently supplies the U.S. with eight times as much electricity as solar and wind energy combined (Tenebaum 1995). The Philippines is a world leader in the application of geothermal energy, with almost 1,800 MW of geothermal generation capacity either in operation or under construction. The Philippines derives more than 20% of its annual electrical energy production from reliable, high-capacity factor geothermal power plants. The Philippine National Power Co. estimates that geothermal power is the country's lowest-cost alternative in power generation (Schochet 1997). Although there are no natural sources of geothermal steam or water within the CSEZ, a new technology of water injection into naturally hot rocks (heated by volcanic activity) is currently in development in the U.S. (Tenebaum, 1995). This hot-dry-rock technology may prove to be an interesting future power source for the geothermal-friendly Philippines.

Another feasible alternative energy source may be existing photovoltaic solar technology. The tropical climate is well suited to the implementation of solar energy programs. For instance, roof solar panels could run all of the air conditioners throughout the CSEZ, and small solar panels could power environmental monitoring and lighting systems at remote locations, where running power lines may be impractical (Lowe *et al.* 1995).

WATER RECYCLING

Water is currently very high on the agenda of the CDC. The water shortage, blamed upon El Niño (*Businessworld* 1998c), has led many businesses to question whether or not a move to the zone is worthwhile if water supply is not guaranteed. The major cause of tension thus far has focused upon the leisure facilities in the subzone, most notably the golf courses (*Businessworld* 1998e). Unless an effective solution to the water problem is found, the capacity of the park to provide leisure facilities, let alone the amenities that are needed for it to flourish, must be questioned.

Present Flows

The zone is currently served by 11 deep wells, providing water to the 224 businesses in the CSEZ (*Businessworld*, 1998a). There is a water treatment plant on the former Air Force Base; however, this was badly damaged by the Mt. Pinatubo eruption and the plant's capacity for water treatment has greatly diminished (Rogelio Magat, personal communication, 1998). As a result, the majority of the wastewater from the site is released into the local rivers without being treated. This situation creates a two-fold problem: the waste of scarce water resources and the potential pollution problems from untreated discharge into rivers and streams. The current scenario can aptly be described as resources "going down the drain" (see Figure 3).

The majority of the wastewater from the site is released into the local rivers without being treated. This situation creates a two-fold problem: the waste of scarce water resources and the potential pollution problems from untreated discharge into rivers and streams.

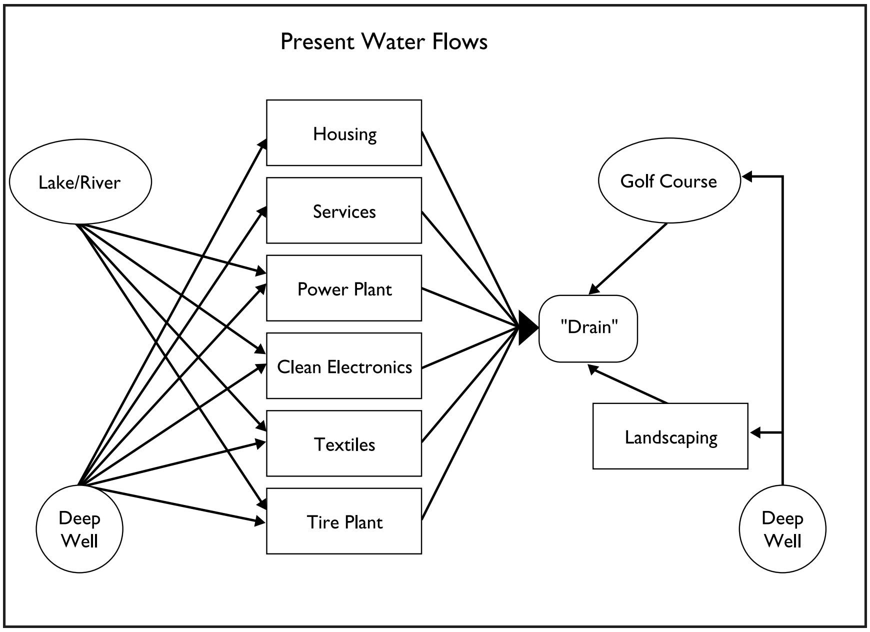

Figure 3 Present Water Flows

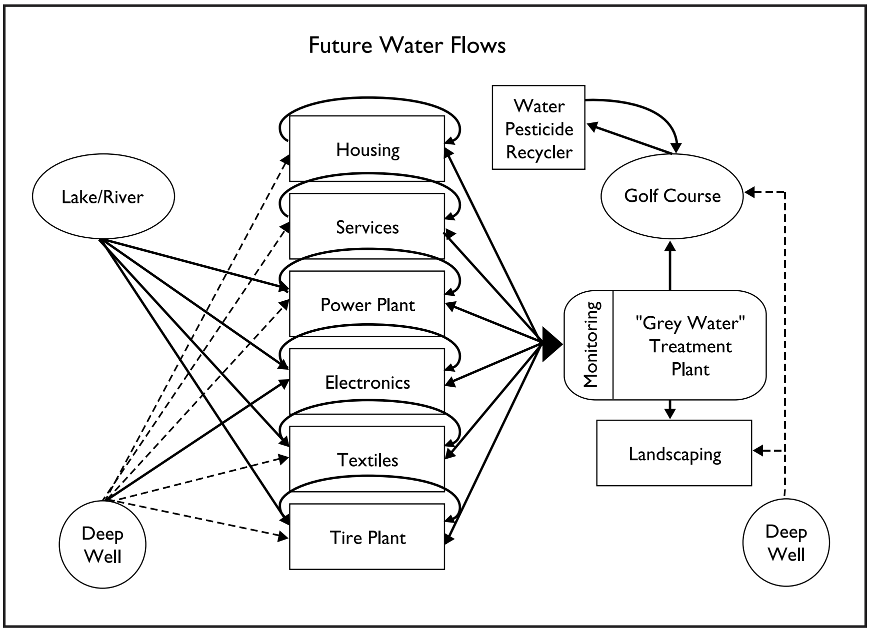

Figure 4 Future Water Flows

Future Flows

The overall goals for using water more efficiently (outlined in Figure 4) are:

- to reduce the amount of water taken from deep wells, using it only where strictly necessary;
- to re-capture and re-use what has previously been considered waste-water, to make up the shortfall.

Water from deep wells is essential in large quantities primarily for just one industry in the park, the electronics industry, although all need it to some degree (if only for safe drinking water). The water for the electronics industry is refined into ultra-clean water, which is necessary for semi-conductor production. The process involves water softening, filtration, reverse osmosis, de-ionization with cation and anion resins, and ultraviolet light exposure (Chase 1995). The underground aquifers are not limitless, and so to ensure a clean water supply not only for the park but also for the surrounding residents of Pampanga, it is essential that the deep well sources are only used where vitally necessary.

Cote *et al.* (1995) suggest that water can be split up into five levels of usage rather than the traditional two of drinking (potable) water and wastewater (sewage). These are:

- ultra-pure water (for use in making semiconductor chips);
- de-ionized water (for use in biological or pharmaceutical processing);
- drinking water (for use in kitchens, cafeterias, water fountains, etc.);
- wash water (to clean delivery trucks, buildings, etc.);
- irrigation water (for use on lawns, shrubs, trees, etc.).

It is in this differentiation that the heart of the proposed solution lies. Cleaning and irrigation water (i.e., gray water) does not need to be at the same standard as drinking water or ultra-pure water. As it is more expensive to clean water to a higher grade, it seems sensible to only clean water to the level required.

The "gray water" treatment plant would ideally be one based on the functioning of a wetland ecosystem. Wetlands are a very effective way to clean water that is dirty or partially contaminated, through a form of bioremediation.

Short-Term Goals

The initial goal is to install a "gray water" treatment plant. Gray water is water that has been used previously and is either still clean enough to be re-used or can be brought up to that standard. For the majority of uses in the eco-park, from power plant cooling to golf course watering, gray water would be of a high enough quality. It should also be noted that often "contaminated freshwater [as is the case in the CSEZ] is of lower quality than the plant's wastewater" (Stringer 1996). Therefore, it can be cheaper to reprocess gray water than to clean supposedly fresh water.

The "gray water" treatment plant would ideally be one based on the functioning of a wetland ecosystem. Wetlands are a very effective way to clean water that is dirty or partially contaminated, through a form of bioremediation. This is particularly effective if the likely contaminants are known and the wetland then can be planted accordingly. It produces its own energy, the material flows are all natural, it uses no noxious chemicals, and is not malodorous. The mechanism itself is therefore ideal in terms of industrial ecology. It is also very low maintenance after its initial creation, thereby reducing future overhead costs for reprocessing.

Such mechanisms are being used successfully in the treatment of industrial wastewater at an M&M Mars plant in Waco, Texas and in Henderson, Nevada –

as well as at a number of municipal sewage treatment facilities including Arcata and San Diego, CA (Cote *et al.* 1995). Whether this could be successful in the CSEZ will depend upon whether there is a suitable site for a wetland, and whether wetlands in a tropical area would provide the same function as those in more temperate regions. Ideally, however, CSEZ could follow the M&M facility's example and provide a natural solution to wastewater treatment. The technique is in its infancy, but there seem to be no major barriers as to why it cannot be used in the CSEZ. Also, if there were a "gray water" treatment plant, then it would be possible to monitor the outputs from each facility to see which might need more direct treatment. The gray water would then be piped back to the industries for their own internal use, as well as to the golf course and the general landscaping of the park to water the fairways and plants respectively.

Recommendations for the Golf Courses

Only one golf course exists at the present time, with three more planned. It should be noted that these golf courses are not a reworking of a savanna landscape, but are being hewn from "virgin forest" (Magat 1998). Golf courses, particularly in the tropics, require large inputs of water and pesticides to keep the greens and fairways looking lush. As a result, they are substantial sources of non-point pollution. However, because the golf courses are being created from scratch, it is possible to turn the non-point source into a point source, simply by lining the ground with an impermeable layer, which gently slopes downhill, and funnels to a collection pipe. Rubber chips from the tire processing facility could then be used as a drainage layer, immediately above the impermeable layer, with the rest of the golf course being built on top. The practice of putting in drainage systems is well established in the U.S., and particularly in areas where water conservation is a major concern (Hellstedt 1998). This system would trap much of the water and unused pesticides that seep through the ground, allowing the water to be reused on the course. This would reduce the need to pipe gray water from the treatment facility and would improve the efficiency of pesticide use. In the long run, economic savings from reduction in pesticide use could offset the initial capital investment for the leachate collection system. Additionally, the leachate collection system would limit the flow of pollution from the golf course into other waterways. Therefore, the CSEZ would reduce its liability for pollution remediation in the future, as well as offer some protection to aquatic ecosystems in the surrounding areas.

Golf courses, particularly in the tropics, require large inputs of water and pesticides to keep the greens and fairways looking lush. As a result, they are substantial sources of non-point pollution.

Long-Term Goals

In the longer term, industries throughout the CSEZ will be encouraged to cycle their water much more tightly. While the management can provide incentives for CSEZ tenants to conserve water resources, the biggest impetus for change would come from an increase in water prices to reflect its scarcity in the region. Current water prices for industrial customers are \$0.9/m^3 and \$0.50/m^3 for commercial customers (*Businessworld* 1997). Increases in these prices may provide some incentive for tighter water cycling. From the outset, the CSEZ should be actively promoting the long-term goal of water resource conservation. The CSEZ undoubtedly will benefit from increased self-sufficiency brought about by efficient water use through internal water cycling (Chin 1996).

The processes needed to facilitate tighter water cycling vary from industry to industry. A brief analysis of two industries outlines this variation. The first looks at recycling in the electronics industry, the second at the housing and services industry.

Electronics

The water needs of a semiconductor facility are substantial. Each wafer produced requires approximately 2,000 gallons of ultra-pure water. For a major facility, including other water requirements, such as cooling towers and scrubbers, this adds up to three million gallons/day. As a result many facilities are using their "waste ultra pure water" in cooling towers and scrubbers, massively reducing their water need. There is also a trend toward recycling the ultra pure water. Though this technique is less widespread due to fears of impurity surges, it is employed in some facilities in Japan (Chase 1995).

One of the fundamental principles of an effective eco-industrial park is the pooling of ubiquitous, low-level waste streams for large-scale recovery and reuse.

Services/Housing

For all uses both the services industry and residential housing are served primarily by water that is of drinking water quality. This is unnecessary because water that has been used for washing does not need to be considered sewage. In an attempt to maximize water use efficiency, buildings are increasingly being designed to incorporate dual pipe systems to separate waste water from gray water (Cote *et al.* 1995). One example of this is the Killington Ski Resort in Vermont. In the mountain lodges, water that has been used in basins provides the water for flushing toilets. This in turn becomes brown water or sewage and is treated as such. The cost of refitting existing plants at the CSEZ may be prohibitive, but as with the golf course, if it can be incorporated at a design stage of new facilities it could provide a huge benefit (Chin 1996).

OIL RECYCLING

One of the fundamental principles of an effective eco-industrial park is the pooling of ubiquitous, low-level waste streams for large-scale recovery and reuse. Used oil waste streams present such an opportunity at the CSEZ. There are two main uses for recycled oil: 1) it can be re-refined at large petroleum refineries and then used in combustion engines and as a lubricant, or 2) it can be burned as fuel, if the proper procedures and equipment are used. Most used oil is used as an industrial fuel source. Given the numerous industrial operations at the CSEZ and the lack of an on-site petroleum refinery, we suggest that used oil become an industrial fuel source at the CSEZ.

The recovery of waste oil makes sense not only from a resource conservation perspective (oil is a non-renewable resource), but also to prevent further contamination of the industrial park. When used oil is dumped onto the ground, down storm sewers, or sent to improperly contained landfills, it migrates into ground and surface waters and has an adverse impact on ecosystems and human health. Films of oil on the surface of water prevent the replenishment of dissolved oxygen, block sunlight, and impair photosynthetic processes. Aquatic species can be adversely affected by oil concentrations as low as one part per million (U.S. EPA 1989). As oil circulates through combustion engines and industrial machines it picks up dirt, rust, and metal particles. In addition, exhaust gases and fluids like antifreeze from engines, and solvents from machinery, can leak into oil. All of these substances increase the used oil's toxicity to humans and to ecosystems. According to the U.S. EPA, one gallon of used oil from a single oil change can ruin one million gallons of fresh water – a year's supply for 50 people (U.S. EPA 1989).

Sources of Used Oil

CSEZ has numerous sources of used oil that make it an ideal candidate for a used oil recovery program. Facilities from which used oil will be generated include:

- Seventy-eight industrial facilities, most of which use oils to lubricate their machines;
- Five utility service facilities;
- CSEZ's Airport, which currently handles 1.5 million passengers per year and is anticipated to have to handle 15 million passengers per year;
- Gas stations;
- Vehicle fleets and individual cars associated with CSEZ's 78 commercial businesses, 28 service industries, 11 tourism businesses, 4 housing ventures (300 housing units currently available, 550 under development), and 2 schools.

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Short-Term Options for Spent Oil Recovery

Studies show that the primary barrier to a successful used oil recovery program is providing an easy way for people and facilities to get rid of used oil they have collected (U.S. EPA 1989). We propose that the Clark Development Corporation contract with a third party or investigate alternative means of establishing an oil collection service. The oil collection service would come to CSEZ industrial facilities, gas stations, and the airport on a bi-weekly basis and to residential housing unit collection areas and other service industries on a monthly basis. In the short-term, trash collection trucks or trucks designed for collection of recyclables could be retrofitted with a used oil collection tank or a rack on which to store containers of used oil (U.S. EPA 1989). In the short-term, this oil could then be exported off-site to a petroleum refinery for recycling or to a facility where it could undergo proper disposal.

Long-Term Options for Used Oil Treatment and Redistribution

Although the short-term oil recovery program would mitigate some potentially serious environmental hazards, it does little to promote the principles of industrial ecology. Over the longer-term, the spent oil must be seen not as a waste but as a valuable resource. For this to happen, the Clark Development Corporation should develop an oil collection, treatment, and redistribution program (see Figure 5). We propose that the oil collection service transport collected oil to an onsite facility for treatment. Ideally, this facility would be located near or in conjunction with CSEZ's 22-hectare petroleum, oil, and lubricant facility, which is currently under construction by the Subic Bay Metropolitan Authority and Coastal Subic Bay Terminal, Inc. Once completed, this fuel storage facility, which has a 570,000-barrel total capacity, will serve the fuel needs of aircraft at CSEZ International Airport. Co-location is also desirable since the used oil treatment and storage facility will be designed to prevent the migration of any oil that might spill onsite.

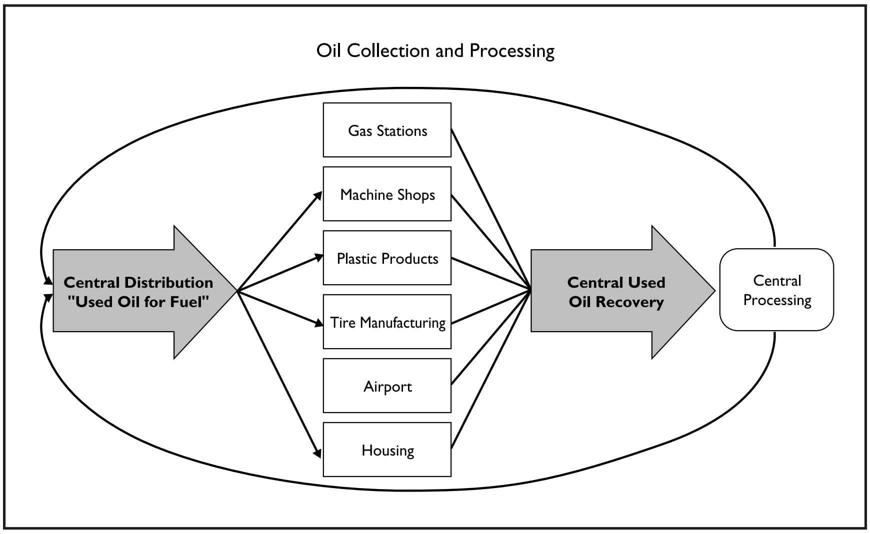

Figure 5 Oil Collection and Processing

Once at the facility, the spent oil would undergo treatment that would allow it to be used as a fuel source (i.e., it would not undergo re-refining for reuse as a lubricant, which is an extensive process requiring full refinery capabilities). For most of the collected oil, a simple oil separation and storage apparatus should suffice (Morris 1993). If the used oil is emulsified, however, a more advanced system called "ultrafiltration" will be required. If high levels of metals or other contaminants are present, a chemical or reverse osmosis unit may be necessary. In both ultrafiltration and osmosis, the waste water that is removed during separation is clean enough to be used directly for gray water and could go to our proposed gray water collection area.

Once treated, the oil could be sold to CSEZ industries with oil boilers for use as a fuel source. The treated oil is actually a preferred fuel source for many industrial facilities. Used oil that has been treated is generally #4 grade oil. This is preferable for fueling purposes over #2 grade because it has a higher BTU value, and preferable over #6 grade oil because it is easier to handle. Many of the industries in the CSEZ are potential candidates for this treated oil. Industries that are likely to have oil boilers include the Yokohama tire facility, tobacco facilities, plastics processors, metal products manufacturers, and the resort facilities. To further encourage used oil recovery, industries that participate in the oil collection program could receive the treated fuel oil at a reduced price.

Education Programs

A key component to the success of this used oil recovery program will be educating industry as well as households in order to gain participation. Used oil collection is relatively straightforward and, once educated, facilities should have little problem implementing collection practices. Most facilities would simply be encouraged to place oil receptacles under their machines, near areas of oil leakage. Households would be taught to collect used oil from their cars, using proper containers to avoid contamination from pre-used bottles or containers. To further minimize the likelihood of contamination of the used oil due to dirty containers, it might be practical for the oil company to provide collection containers to those participating in the program. This would also minimize the generation of additional hazardous waste, which would result from the disposal of oil collection containers.

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SOLVENT RECYCLING

Industrial solvents include a wide variety of chemical compounds used in various manufacturing steps in the electronics, plastics, textiles, metal working, tool manufacture, rubber manufacture, and various other industries. Chlorinated and fluorinated solvents such as TCA, TCE, and CFCs are declining in use due to their ozone depleting properties. Industry must find technological solutions to questions of recyclability of new industrial solvents, such as the alcohol-based solvents methanol and acetone, which still pose environmental threats (Morris and Roberts 1993). Of the estimated 3.5 billion gallons per year of solvents produced in Canada and the U.S., almost two-thirds is consumed or is otherwise unavailable for reclamation. That leaves slightly more than 1 billion gallons per year that must be disposed of, most of which ends up being incinerated. Less than 10% of total annual production is refined and returned to commerce (Morris and Roberts 1993).

To reduce the toxic releases and to adhere to the eco-industrial park concept of closing loops in waste streams, there may be possibilities for centralized collection and recycling of industrial solvents at the CSEZ. The concept of encouraging a solvent recycler to locate in an eco-industrial park has been recommended by the Environmental Defense Fund for the Brownsville Eco-Industrial Park, in Brownsville, Texas/Matamoros, Mexico (Cohen-Rosenthal *et al.* 1996). Before describing the proposed flows of waste solvents in the CSEZ, the common methods of solvent recycling will be investigated.

Solvent Recycling Methods

The basic technology used to recycle solvents has not changed significantly in the last 50 years. The solvent-laden waste is boiled in a distillation unit to separate the solvent from the residual water and solid wastes. After vaporization, the gaseous solvents pass through a condenser to re-generate clean, recycled solvents. Distillation units use a batch system that handles one unit of solvent at a time (for instance, a 55 gallon drum) or a continuous feeding system that accepts a continuous flow of waste solvents without exchanging input batches or interrupting the recovery process (Coatings 1995). Distillation units can commonly handle a variety of solvents with boiling points ranging from low temperatures to solvents with boiling points well above 150°C (300°F) (Burke 1991).

The percentage of solvents that can be recovered from waste streams varies, although 70-80% is a reasonable industry average (U.S. EPA 1997). While 100 % of the solvent could theoretically be recovered, it is not economically or logistically practical. As the clean solvent is boiled off, the residual liquid becomes increasingly thicker. In theory, all of the liquid solvent could be driven off with increasing heat inputs, until a solid, solvent-free residue remained. However, the energy inputs and the logistical problems of equipment cleaning and maintenance prevent complete solvent recovery (Coatings 1995).

One of the most significant benefits of recycling solvents is cost savings. There are two general options available for industrial solvent recycling: 1) installing an in-house recycling unit or 2) sending waste material to a large scale solvent recycling company. The EPA estimates that in-house solvent recycling machines run from $12,000 for a 20 gallon batch unit, to $15,000 for a continuous feed, closed-loop system accepting 55 gallon drum inputs (U.S. EPA 1996). While there is a cost to recycling solvents, in most cases it is less than the total cost of disposing waste solvents and buying virgin solvent inputs (Coatings 1995). Solvent recyclers typically pay for themselves within a few years of installation, or in some cases within months of installation, depending on the volumes of solvents recycled (Burke 1991).

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Larger specialized solvent recycling facilities handle the majority of solvents recycled in the U.S. and Canada. Van Waters & Rogers (Kirkland, WA) and Ashland Chemical (Columbus, OH), two major global distributors of solvents, are also the main recycling collectors and consolidators in the United States. The companies were in a perfect position to develop "reverse distribution" because they already had the trucking and rail distribution infrastructure and expertise. Ashland and VW&R, however, do not perform any treatment themselves. Rather, they rely on contracts with treatment firms, including Laidlaw Environmental Services (Columbia, SC), Safety-Kleen (Elgin, IL), Southdown (Houston), and Chemical Waste Management (Oak Brook, IL) (Morris and Roberts 1993). Recycling companies have support equipment and mechanical technicians to overcome problems in the recycling process, and may prove more cost effective than on-site recyclers (U.S. EPA 1997). Recycling companies can employ advanced technologies to increase recovery, including equipment to eliminate moisture in solvents and fractionation towers that separate blends of solvents to achieve higher purity. These larger solvent recycling facilities may cost upwards of $1 million (Coatings 1995).

A central solvent recycling facility may be the more cost-effective option. The eco-industrial park concept seeks to centralize infrastructure that not all industries could afford themselves, offering economic advantages due to economies of scale. Established solvent recycling companies can be encouraged to locate in the CSEZ, with a steady supply of incoming solvents as a positive economic incentive.

Solvent Flows

The flow diagram in Figure 6 represents a simple and theoretically cost-effective program to reduce overall solvent use. At the beginning of the flow cycle, the 13 electronics industrial facilities in the CDC use the "cleanest" (most pure) solvents, that may be transferred directly to other industries. This is a "downcycling" of solvent use from a high-grade application to lower-grade applications (Lowe *et al.* 1995). A similar scenario has been implemented by Ashland Chemical (Columbus, OH), one of the major global distributors, recycling collectors, and consolidators of solvents, and provider of ultrahigh-purity solvents to semiconductor manufacturers. The semiconductor production process leaves solvents very pure. Ashland Chemical recollects the nearly pure waste solvents, and resells the solvents to industrial customers at a reduced price (Morris and Roberts 1993). The eco-industrial park ideal suggested here would remove the solvent middleman.

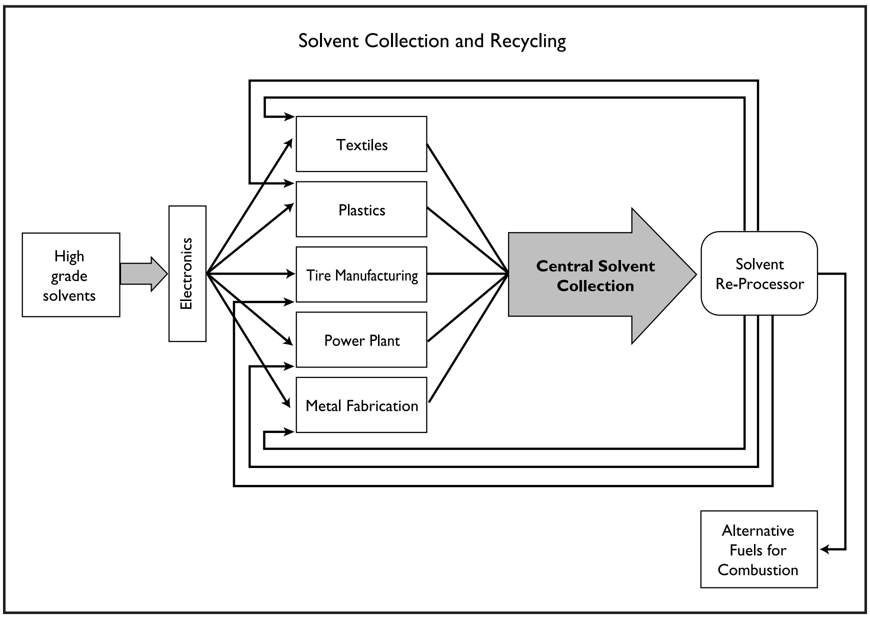

Figure 6 Solvent Collection and Recycling

The low-grade waste solvents from the general industrial ecosystem can be transferred to a central solvent recycling facility. This centralized solvent recycling facility may be better suited to create transfers of used solvents to industries desiring alternatives to fossil fuels for combustion (Morris and Roberts 1993). Commonly, waste oil recyclers accept low-grade waste solvents. The low-grade industrial solvents could enter the larger waste oil recovery system described earlier in this document.

Short-Term Possibilities for Solvent Recovery

Using low-grade recovered solvents as a feedstock for fossil fuel boilers is a closed loop, although it is a transfer of a water emission to an air emission. However, there are emerging new technologies to recover low-grade solvents from residual wastes. For example, liquid nitrogen condensation and separation of pure solvent from the residual gaseous waste matrix can recover up to 99% of solvents in a waste stream, in pure form (Monroe 1997). Special facilities can distill various types of solvents, and regenerate the highest quality new solvents to return back to the industrial ecosystem. This reduction of virgin solvent inputs would represent a significant monetary savings, especially considering the volatility of the Asian financial markets, and the reliance on foreign trade for solvent chemicals.

Long-Term Trends for Zero Solvent Waste

The creation of a solvent recycling infrastructure is a short-term solution to the general problem of solvent use. Applying general industrial ecology principles may remove the need for solvent recycling, if industry moves towards zero solvent waste or zero solvent use technologies. Initiation of intensive internal solvent recycling programs, introduction of ozone based solvents, and implementation of water-based washing techniques would eventually reduce the feedstock to the solvent-recycling infrastructure. However, for the next 10-20 years, a solvent recycling facility is a viable option with available technology.

COMPOSTING

Composting would seem the ideal solution to utilizing some of the waste streams at the CSEZ, because it is a natural process, with which many people are already very familiar. Indeed there is already a small degree of “grasscycling” composting being carried out on the site by those who tend to the grounds (Magat 1998). We are therefore looking to expand this informal reprocessing into a more centralized system that can transform the waste from the tobacco industry, landscaping, greenhouses, and golf courses into valuable inputs to the system.

There are two tobacco companies operating at the CSEZ, and their waste is currently being transferred to a landfill. Special emphasis was placed on this industrial sector because the waste was similar enough to that being created by the greenhouses and golf courses that it would not have to be sorted prior to being composted.

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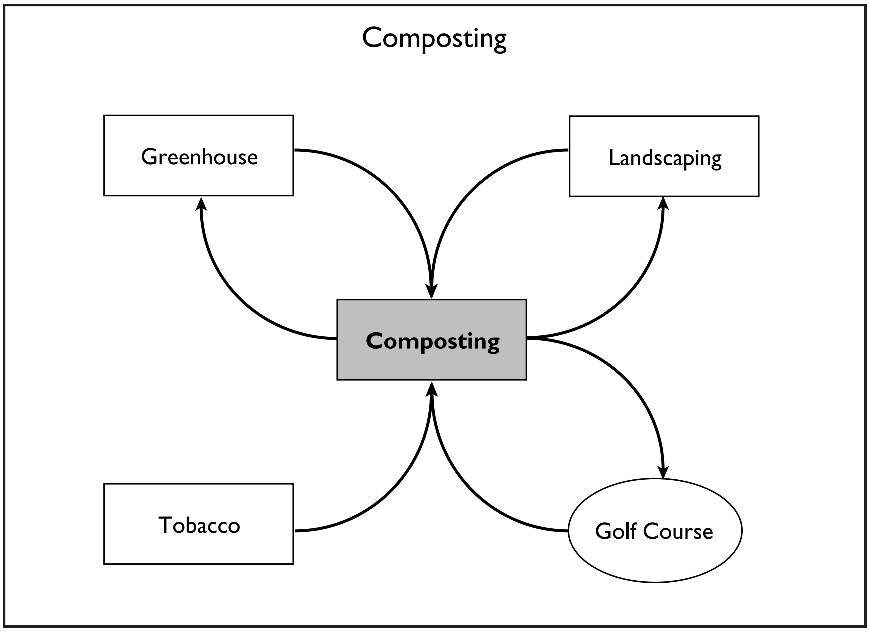

Figure 7 Composting

Composting Technologies

A common approach to compost management is to install a centralized processing facility and so create an economy of scale through reducing labor costs, which on average make up 29% of the costs of a U.S. facility (Simson and Connelly 1994). However, due to the low labor costs in the Philippines, this economy of scale does not transfer. Therefore, it is more sensible to encourage smaller composting operations at each individual site. In addition, smaller facilities mitigate the major problem of compost odor. This occurs when the compost starts to decay anaerobically, rather than aerobically, which was a major problem at the Reuters' Pembroke Pines facility (*Waste Age* 1993).

The most common technology utilized in solving odor problems is biofiltration. Biofiltration involves directing an air stream through a series of perforated pipes into a bed of organic media, which effectively removes the malodorous compounds. Costing between $1,000 and $2,000 per cubic yard of compost, plus $5-10 of annual operation and maintenance per cubic yard of compost, biofiltration may not be economically feasible (Aquino 1996). Again, this makes the larger facility a less attractive option.

The most suitable form of composting in the CSEZ would therefore be small-scale units associated with each facility. Not only would this reduce the potential problems of malodor, but it would cut down on transportation expenses. The tobacco companies could sell their unprocessed tobacco leaf waste or compost of the same to partner firms, as they do not have a direct use for compost.

Long-Term Flows

This investigation has been limited to a select few industries in the CSEZ that produce organic matter suitable for composting. In the future, many more organic residues can be composted, including by-products of wood manufacture, food-, paper-, textile-, cement- production, and construction/demolition (Cote *et al.* 1995). There are toxicity issues regarding composting that will have to be dealt with before implementing such a wide-ranging composting initiative. If municipal solid waste is to be composted, there needs to be very careful screening of inputs to prevent contamination from toxic wastes. This usually is combated by initial source separation, however, this is very labor intensive and adds dramatically to the costs of composting.

There are numerous instances where composting of low-grade paper, cotton, and other organics has demonstrated economic advantages over their use as raw material in marginal recycled products (Cote *et al.* 1994). However, until total costs of waste disposal are actually reflected in the tipping fees, composting of this kind may not be economically viable (Aquino 1996).

SCRAP TIRE RECYCLING

The industries and infrastructure development at the CSEZ present great opportunities for applying the principles of industrial ecology to "close the loop" on material flows associated with tire manufacturing within the industrial park. Finding uses for scrap tires promotes fundamental principles of industrial ecology such as recycling natural resources that are in limited supply (i.e., the large quantity of petroleum in tires), preserving the tire's embedded energy, and turning a "waste" into an input. In addition, recycling tire wastes can prevent human health and safety hazards that are associated with the disposal of tires in landfills and in open stockpiles.

Tires are not well suited for landfill disposal because they tend to migrate to the top and can pierce the landfill cover. In addition, the open crevices in whole tires harbor pockets of landfill gas and make them an inefficient use of landfill space. For such reasons, 35 states in the U.S. have banned the disposal of whole tires in landfills (RMA 1998). At the same time, simply stockpiling scrap tires creates potential health hazards such as mosquito infestation, which can lead to the increased spread of disease, and risk of fire. Tire piles that catch fire can create significant water and air pollution and are difficult to extinguish.

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Fortunately these hazards can be avoided because there are many opportunities for scrap tire reuse within the CSEZ. There are two main forms in which scrap tires can be reused. The first, and simpler option, is to find direct uses for whole scrap tires. The second and more cost-intensive reuse options require that the tires be "shredded" into rubber chips (generally two inches in diameter) or rubber crumb (approximately the consistency of small gravel or coarse sand).

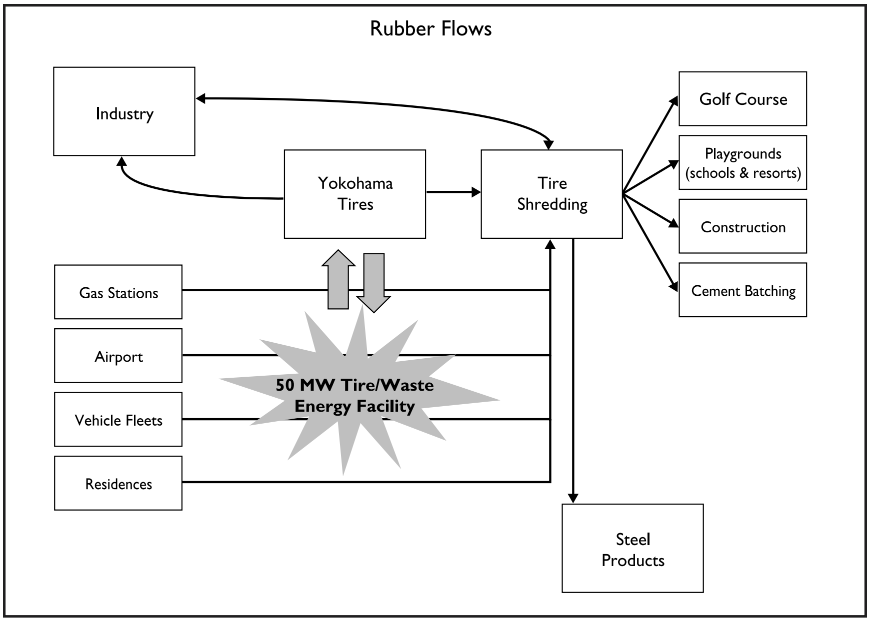

Figure 8 Rubber Flows

Yokohama Tire Plant

The cornerstone of the proposed CSEZ tire reuse effort is the industrial park's multinational Yokohama tire manufacturing facility. The four-acre Yokohama facility is located on 16.5 acres of land in Industrial Estate 5 of the CSEZ main zone. The plant's design resembles the basic layout of a tire manufacturing plant, incorporating the four tire manufacturing processes – materials preparation, tire building, curing, and finishing. Yokohama's system uses nine assembly lines capable of producing 51 different sizes of tires. The plant began operating on January 7, 1998. It currently generates 5,000 tires per day and will have manufactured approximately 1.2 million tires by the end of 1998. The Yokohama plant will be generating 10,000 tires per day (3.65 million tires per year) by 2001.

Like any tire manufacturing facility, the Yokohama plant produces rubber residues, which can be used as inputs to other processes. These residues include:

- pre-cured, off-specification rubber mixtures;
- pre-cured, off-specification tires (i.e., "green tires");
- cured, off-specification tires.

Although there are opportunities to reuse off-specification rubber mixtures and green tires, the following recommendations focus on the use of cured, off-specification tires, because these residues present the greatest opportunity for cycle improvement at the CSEZ. Pre-cured off-specification rubber mixtures (usually in the form of rubber slabs) can generally not be recycled back into the tire manufacturing process because the mixture is not of high enough quality. These mixtures can however be used to make low-stress, low-dynamic rubber products such as floor mats and bumpers. If Yokohama does not have in-house capabilities to make such "side products," efforts should be made to sell these mixtures to other rubber product manufacturing facilities. Green tires present more of a reuse problem because they are bound with fabrics, wires, and beads.

The Scrap Tire Management Council, a Washington D.C.-based trade association, estimates that for a given state-of-the-art tire manufacturing facility, between 3 and 4% of its tires will be off-specification. Up to one half of these off-specification tires are deemed so for cosmetic reasons and are still sold in many developing countries at reduced prices. Assuming Yokohama engages in such sales, one can still conclude that the Yokohama plant will generate between 18,000 and 24,000 scrap tires by the end of 1998, and once operating at full capacity, will generate between 56,750 and 75,000 scrap tires per year.

Other Sources

Next to the Yokohama facility, the next largest generator of scrap tires at the CSEZ is the airport. In addition to tires from the airport's maintenance and transportation vehicles, the airplanes regularly replace their tires (Serungard 1998). Other sources of scrap tires within the CSEZ include gas stations and automotive repair facilities; vehicle fleets from infrastructure development efforts, transport of manufactured goods, and public transportation within the CSEZ; and residents' vehicles. When all of these sources are accounted for, CSEZ emerges as a major source of scrap tires.

Short-Term Options for Scrap Tire Reuse

Whenever possible, the use of whole scrap tires should be encouraged. Some examples of possible uses for whole scrap tires at CSEZ include playground equipment such as tire swings and sandboxes (particularly the larger tires from trucks and airport vehicles) at the CSEZ-Philippines International School of Asia and the Grissom School. The resorts may also have playground facilities that could make use of these tires. Other uses for whole tires include roadway crash barriers (which would be particularly helpful at the CSEZ given the extensive on-going construction) and dock bumpers. While reusing whole scrap tires requires minimal transportation costs (short-range transportation within the CSEZ) and transaction costs, these uses will only account for a very small percentage of CSEZ's scrap tire stock.

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Long-Term Options for Tire Reuse

Given the magnitude of scrap tire outputs from the Yokohama facility, airport, and other facilities within the CSEZ, and the numerous uses for shredded tires within the site, investing in tire shedding equipment seems to make economic and environmental sense. Most large tire manufacturing facilities, such as Yokohama, do not actually shred their own tire scrap; rather, they enter into an agreement with a third party. Under such an arrangement, a third party "tire shredder" would set up a facility near the Yokohama plant and enter into a contractual agreement to have rights to Yokohama's scrap tires. The cost of very basic tire shedding machinery is $100,000 to $150,000; however, scrap tire experts state that such machines would not be able to handle the magnitude of tires generated at the CSEZ (Serungard 1998). The type of machine needed at the CSEZ would have operating costs in the range of a $400,000 to $700,000 a year. Given the diversity of shredded-tire markets at the CSEZ and throughout the Philippines, such an operation could be profitable. Following are brief discussions of some of the opportunities that exist at the CSEZ for using tire chips produced by a shredding facility.

Tire-Derived Fuel

Perhaps the best use of shredded tires is as fuel. Tires have 40% more energy value per pound than coal and an energy value roughly equal to that of oil (approximately 12,000 to 16,000 BTU per pound) (Goodyear 1998). Tires are a good fuel source because they are almost entirely made from petroleum. Most tires are made from synthetic rubber, which is produced from crude oil, carbon black, also produced from crude oil, petrochemicals, extender oils and organic fabric, produced from crude oil, and steel. At high temperatures, the steel in the tires oxidizes to produce 3,500 BTU per pound. Tires burn cleaner than coal, but some emissions will result from combustion and all facilities burning should test these emissions and put the appropriate control mechanisms in place.

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Combustion facilities that currently use tire-derived fuel (TDF) include power plants, tire manufacturing facilities, and cement kilns. Because they operate at very high temperatures, cement kilns can thoroughly combust scrap tires. Also, cement production can utilize the iron oxide that results from the combustion of the steel contained in tires, steel belts, and beads. Not many facilities in the U.S. use tires because of the low cost of energy and low shredded tire disposal fees, but tires are widely used in Europe to fuel cement kilns. CSEZ currently has two cement batching plants: R.D. Policarpio & Co., Inc., and New Sampaguita Builders Construction, Inc..

Another longer-term option at the CSEZ is to retrofit the old 50 MW plant to be a TDF and waste-to-energy facility.

Golf Course Drainage

Tire chips can be used to achieve better drainage on the three CSEZ golf courses. As discussed in the water recycling portion of this paper, a layer of tire chips could be placed below the surface and above a liner on the golf courses to facilitate drainage and collection of the waste water leachate. Tire chips that are two inches in diameter have a hydrologic conductivity of approximately 1x10 cm/sec and provide an excellent medium for leachate collection (*Waste Age* 1996).

School Yard Groundcover

Tire chips can be used instead of gravel in playgrounds as a groundcover. They are safer than gravel in that they provide a softer cushion for children.

Construction Materials

Tire chips have many characteristics that make them excellent for use in construction projects. They can be used in place of many conventional construction materials such as sand, gravel, stone, and clean fill. Tire chips are one-third to one-half as heavy as gravel, are sound thermal insulators, and provide good drainage (generally 10 to 100 times better than many soils). Many contractors use tire chips as lightweight fill for retaining wall backfill, as insulating layers, as daily landfill cover material, for leachate collection aggregate, septic fill aggregate, and as roadbed material. Given the magnitude of infrastructure and facility construction underway at the CSEZ, these projects could serve as a great receptor for a substantial volume of tire chips (Powell 1996).

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Tire Wire Recycling

In addition to the rubber, the steel used to make tire belts and beads is also a valuable residue. About 10% by weight of a scrap tire is steel wire. Many tire-shredding facilities recover this material because it is high-quality, high-carbon, high-strength steel (EPA 1989). One problem associated with wire recovery is that it can be difficult to detach all the rubber from the wire; however, many shredding facilities are improving their ability to do this (Goodyear 1998). Scafforms International Manufacturing and Trading Corporation, which is located in CSEZ, manufactures steel scaffolding and accessories for export. This facility may have use for these high-quality steel residues in its manufacturing process. If not, the tire shredding facility should still recover this steel and try to export it to a steel mill in the Philippines.

CONCLUSION

In recalling the initial representation of the disjointed existence of industrial residents at the CSEZ, the intricacy of the possible materials and energy flows model is impressive and overwhelming.

When coupled with the many possibilities for exchange that remain to be integrated into this model, it is easy to see how the execution of such a plan can get very complicated. However, if planned well, the evolution of the CSEZ industrial park into an eco-industrial park can be a rewarding process with successful results.

In order to undertake the conversion of the CSEZ, there are a few major decisions to be made about how best to organize and develop the project. Will the Clark Development Corporation carry the project or follow the example set by Kalundborg, allowing the actors to take ownership? Who will pay for capital expenditure and maintenance costs? These are questions that must be resolved as the project progresses.

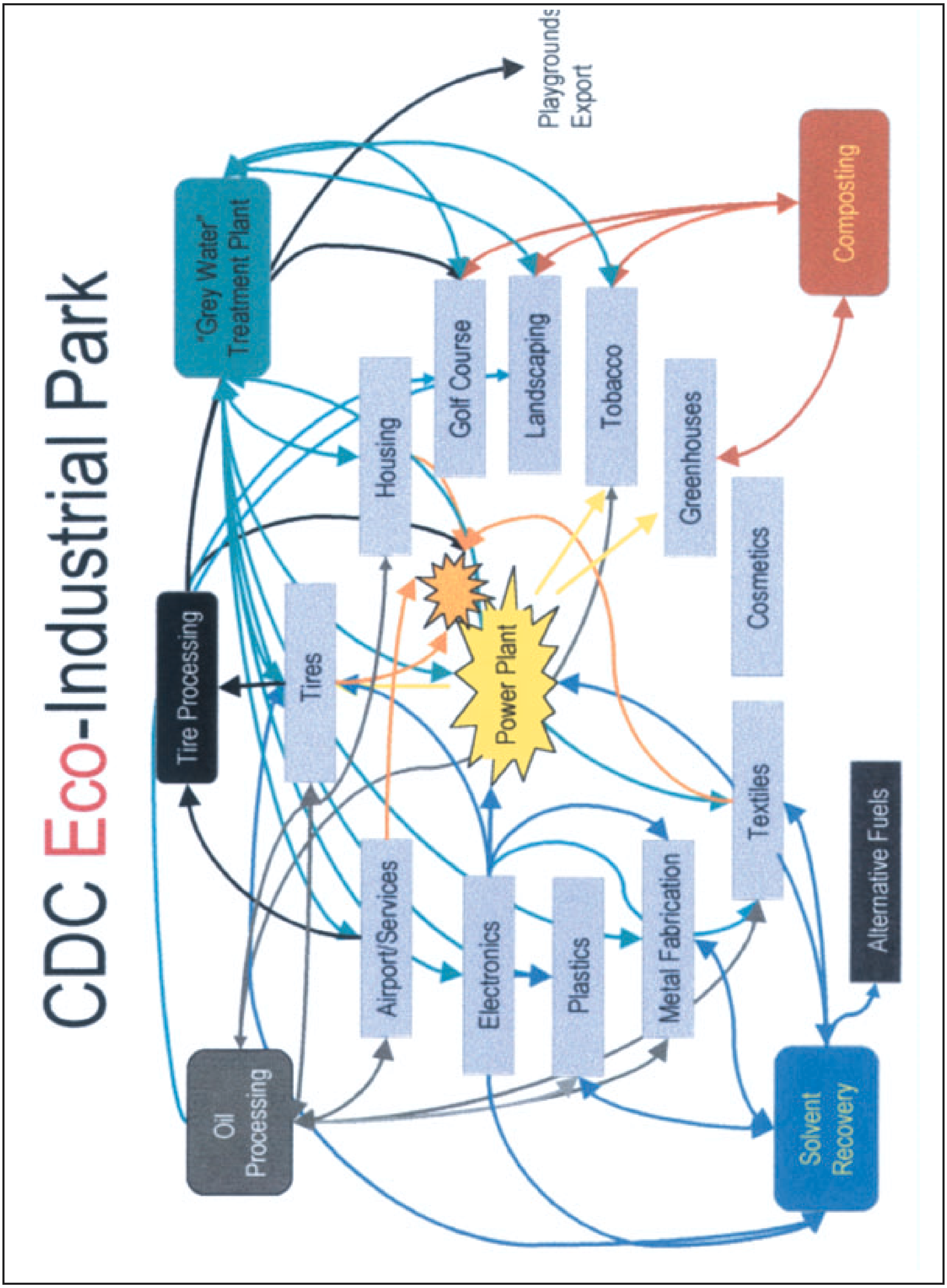

Figure 9 CDC Eco-Industrial Park

The question of initiative and capital funds for the energy cascading piping systems and centralized processing units (CPUs), i.e., the solvent and oil recycling and waste water treatment facilities, will have to be decided fairly early on. Some options include:

- Invite new firms to come in and take over the central processing roles, asking fair market value for their services;
- Allow the Clark Development Corporation to develop and take over management of the CPU services, levying fees for per unit usage of the services, and covering the capital expenditures for installment from resident fees. The same could be true of the energy cascading system;
- Look to public entities for support. Given that clean water and energy provisions are responsibilities of public utilities, they gain from the efficiency and treatment measures adopted by an industrial ecology effort (Kalundborg received such support from the local government);
- Designate responsibility to firms for raising capital for the construction of the energy transport mechanisms and facilities using a variety of methods for payment of services including tradable permits.

Regardless of the path taken, there are two steps that, if taken from the start, could prove beneficial throughout the development of the EIP: 1) provide education on applied industrial ecology and 2) solicit input and participation from member firms.

The provision of educational materials and training sessions on industrial ecology concepts and applicable tools is the first step to ensure that an EIP can be established. If the resident firms do not understand and espouse the larger goals of sustainability and the means to achieve them, they are more likely to reject the effort.

At present, many companies fail to realize that their wastes are marketable (Dwortzan 1998). Research conducted at Cornell University shows that when employees are encouraged to participate in the larger industrial ecology effort and are educated about the goals and potential outcomes, the companies have achieved reductions in materials consumption up to three to four times higher than without taking this step (Cohen-Rosenthal 1996).

Once education on the basics of sustainability and industrial ecology concepts has been provided, the CDC would do well to make information available about more advanced industrial ecology concepts and tools such as design for environment (DFE), total quality management (TQM), sustainable architecture and design, and life-cycle analysis (LCA). The educational materials could be distributed, or an educational center could be established where participants would have access to reference materials and be invited to attend training sessions. Of particular relevance to an educational effort at the CSEZ is the presence of the "Private-Sector Involvement in Environmental Management" project in the Philippines (Hamner 1998). This project, sponsored by the United Nations Development Programme, and the first of its kind in Southeast Asia, includes training in industrial ecology concepts and a pilot industrial ecology project (Hamner 1998).

Once the CSEZ employees have a general understanding of industrial ecology, they should be surveyed to determine their level of interest, environmental and economic priorities, ideas for development, potential for exchange, and level of commitment to the project, i.e., if they would be willing to serve on any committees or educational teams. This information will serve as an excellent base from which to start the planning process and project implementation. In addition, should any conflicts arise over decisions about the larger park, the CDC can reference the information provided via the surveys.

Barriers to Success

It is instructive to point out that there are several challenges to successful EIP development:

- There are risks associated with the failure of a supplier or receiver within the park;
- Neighbors to the EIP can impact the environmental resources that the industrial ecology model seeks to protect;
- Firms rarely keep close track of their metabolism of materials and energy. This is information that is required in evaluating potential for park-wide efforts as well as bilateral agreements. Therefore, firms often have to invest in information gathering, which can be a costly and time-consuming process;
- When firms have the information, they are often unwilling to share it for fear of losing competitive advantage.

Once the CSEZ employees have a general understanding of industrial ecology, they should be surveyed to determine their level of interest, environmental and economic priorities, ideas for development, potential for exchange, and level of commitment to the project, i.e., if they would be willing to serve on any committees or educational teams. This information will serve as an excellent base from which to start the planning process and project implementation.

Recognizing that these barriers exist is half the battle to overcoming them. Many of them can be surmounted with time as relationships based on trust, understanding, and mutual benefits are built.

Long-Term Goals

The CDC will want to consider a few long-term goals during the planning process and throughout the development of the EIP. One such consideration will be whether the CDC and CSEZ partners will target "filler" industries for location at the park. This would be an effort to tighten the closure on the EIP loop to move toward the idealistic goal of zero waste production. Partner firms would be invited to identify their remaining waste streams from which an analysis could be conducted to highlight industries that would be a good "match" for receiving the byproducts.

Targeted industries often play the role of the "decomposer" in the industrial ecosystem (Lowe *et al.* 1995). In a natural ecosystem, decomposing organisms take the final key step in "closing the loop" by breaking down the waste materials from other production processes and then discarding them in a useable, available medium to be consumed by another actor for the next cycle of production.

This process of niche-filling will be ongoing because, again, like natural ecosystems, markets are dynamic even when they are stable (Lowe *et al.* 1995). In addition, it is important that once the target industries have been identified, the CDC should screen specific firms for quality assurance purposes. Basically, the CDC would seek firms that embrace the larger ecological goals of the park, and would be willing to work with on-site firms in developing materials exchange agreements. This suggests that the CDC would have its choice of several firms from a given industry. While this may not be the case at first, it is likely that the reputation accompanying EIP status will bring more than enough willing potential partners to the table.

In addition to the long-term goal of targeting industries, and those proposed throughout this paper, the CSEZ may want to consider greater incorporation of on-site service industries in materials and energy exchange, and the advancement of industrial ecology practices within firms, using the tools discussed in the educational proposal.

The president of the Philippines has hailed the CSEZ as the nation's development leader. The conversion of the park to an economically and environmentally sustainable EIP will only elevate its visibility and leadership role throughout the world. Already, the Chinese government has shown interest in the CSEZ as a potential model for brownfields redevelopment. All of the evidence presented here points to the conclusion that the CSEZ has great potential to become the "Kalundborg of the Developing World."

REFERENCES

Aquino, J.T. 1996. Composting: The Next Step? *Waste Age*, March 1996.

American Petroleum Institute, 1998. <<www.api.org >>

Blumenthal, Michael, and John Serumgard. March 1996. Scrap tire markets still rollin' along. *Resource Recycling*. Vol. 15, No. 3.

Burke, Simon. 1991. Recovering dirty solvents – a new approach. *Ink & Print*, 9(2): 10.

Businessworld – Philippines. November 10th, 1997. 'Clark firms to avail of lower water rates.'

Businessworld – Philippines. January 9th, 1998. 'Jamboree site taps new deep well'.

Businessworld – Philippines. March 9th, 1998. 'Two golf course projects gain permits'.

Businessworld – Philippines. March 18th, 1998. 'NGO warns against continuing land conversion in Clark ecozone'.

Businessworld – Philippines. April 3rd, 1998. 'Mondragon assails CDC over golf course project.'

Chase, V. 1995. 'Distilled wisdom on ultrapure water recycling', R&D 37(7), 61-63).

Chemical Business Newsbase, March 10, 1988. Yokohama Tire Philippines commences operations as tire export base to Europe, Asia, and Middle East.

Chin, J. 1996. 'Water Efficiency in Industry' *Chemical Week*, August 14th, 1996.

Coatings, November 1995. Recycling solvents is one way to reduce costs. 16(2):72.

Cohen-Rosenthal, Ed, Tad McGalliard, and Michelle Bell. 1996. *Designing Eco-Industrial Parks: The North American Experience.* << www.cfe.comell.edu/WEI/design.html >>

Cote, R.P., R. Ellison, J. Grant, J. Hall, P. Klynstra, M. Martin, and P. Wade. 1994. *Designing and Operating Industrial Parks as Ecosystems*. Nova Scotia. Dalhousie University Press.

Director. September 1997. Letting off steam, 51(2)-69.

Dwortzan, Mark. January 11, 1998. The greening of industrial parks. *Massachusetts Institute of Technology Alumni Association Technology Review*, 100(9):18.

Ehrenfeld, John and Nicholas Gertler. 1997. Industrial Ecology in Practice: The evolution of interdependence at Kalundborg. *Journal of Industrial Ecology*, I(I): 67-79.

Ellis, William, 1997. Lecture notes for *Environmental Aspects of the Technological Society*, course at Yale School of Forestry & Environmental Studies.

Gertler, Nicholas and John Ehrenfeld. February/March 1996. A down-to-earth approach to clean production. *Technology Review*. 50: 49-54.

Gertler, Nicholas and John Ehrenfeld. 1997. Industrial Ecology in Practice. The Evolution of Interdependence at Kalundborg. *Journal of Industrial Ecology*. 1(l)-.67-79.

Goodyear Tires, 1998. << www.goodyear.com >>

Hamner, Burton, 1998. Industrial Ecology in East Asia. J*ournal of Industrial Ecology*, 2(3). Draft.

Hennagir, Tim, 1998. Combined Heat and Power (CHP's) Promise. *Independent Energy*, 28(l)-38-40.

Ignatz-Hoover, Frederick, John S. Dick, and Otto W. Maender. 1996. The effect of HTS on cure kinetics of accelerated sulfur vulcanization. *Rubber World*, 214(5):19.

Kearney, AT. September 11, 1990. Scrap Tire Management Council: Scrap Tire Use/Disposal Study, Final Report.

Kashiwa, Takao. 1996. Future direction and prospects of energy and environment related R&D. http://club.jpn.net/infomofa/opinions/kasiwagi.html

Kasprzak, Kenneth A., 1996. Emulsion techniques using silicone formulation aids personal care products. *Drug & Cosmetic Industry*, 158(5): 39.

Lowe, Ernest, Steven R. Moran, and Douglas B. Holmes. 1995. Fieldbook for the development of eco-industrial parks. Draft.

Magat, Rogelio. 1998. Clark Development Corporation. Personal communication.

Morris, Bill. 1998. Advanced Liquid Recycling/United Industries. Personal communication.

Morris, Gregory and Michael Roberts. August 25/September 1, 1993. Solvents: some recovery in recovery. *Chemical Week*.

Monroe, Charles. June 1997. Making solvent recovery more cost-effective. *Manufacturing Chemist*.

National Oil Recyclers Association, 1998. << www.noraoil.org >>

Norman, David A. 1996. Review of processing equipment and introduction to mixing processes and equipment in rubber industry. *Rubber World*, 213(5)-.20.

Petroleum Times, 1996. Co-generation: UK growth is catching Europe. 16(21):7.

Powell, Jerry. December 1996. The hottest trends in tire recycling. *Resource Recycling*.15(12).

Schochet, Daniel N. 1997. Philippines fast track. *Independent Energy*, 27(8): 54-56.

Simson & Connelly, 1994, 'The economics of composting', Waste Age, pg. 264.

Serungard, John. 1998. Scrap Tire Management Council. Personal communication.

Stringer, J. 1996, 'Industry interested but slow to move', *Chemical Week*, August 14th, 1996.

Tenebaum, David. 1995. Tapping the fire down below; hot dry rock energy. *Technology Review*, 98(l)38,

Thomberry, K. 1997, 'Stemming the tide of wastewater' *The Business Journal*, 27(15), pp.33-35.

Tuccio, Al. 1994. Is peroxide/co-agent curing for you? *Rubber World*, 209(5): 34.

U.S. EPA. 1996. Cleaner technologies substitutes assessment: Lithographic blanket washes. EPA Design for Environment lithography project. www.epa.gov/docs/fedrgstr/EPA-TOX/1996/August/Day-07/pr-24172DIR/Support.htm

U.S. EPA. 1997. Pollution Prevention Opportunity Solvents. <www.epa.f4ov/oirntrnt/intrnip2/p2/opprtnty/solvents.htm >

U.S. EPA, OSWER, May 1989. How to Set Up a Local Program To Recycle Used Oil.EPA/530-SW-89-039A.

U.S. EPA, OSWER, October 1991. Summary of Markets for Scrap Tires. EPA/530-SW-90-074B.

Waste Age. August 1993.

Waste Age. March 1996. Alternative Materials.

Wolfe, Paris R. September 1992. Economics of used oil recycling still slippery. *Resource Recycling*. 11(9).

Part II: Strategies and Opportunities

Connecticut Newsprint: A Conceptual Model for Eco-Industrial Material Flows 1998

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ABSTRACT
The primary objective of this analysis is to apply the concepts of industrial ecology and eco-industrial parks (EIP) to the future development plans of Connecticut Newsprint LLC, a newly formed company based in Bridgeport, Connecticut. At the request of Connecticut Newsprint's President and Chief Executive Officer, James L. Austin, our principal task was to evaluate alternative means to utilize the company's short-fiber sludge, a byproduct of the recycled newsprint operation. Our group has evolved the "problem" of sludge disposal in the short-term into an "opportunity" for significant business development and diversification over the long-term. The present analysis proposes a development plan that uses the recycled newsprint facility as the basis for forming an EIP.

INTRODUCTION

Industrial Ecology and the Eco-Industrial Park (EIP) Concept

In recent decades, environmental issues have leapt from the status of peripheral concern in the minds of corporate managers to become significant factors in the design, operation, and eventual disassembly of industrial processes and products. Internal evaluation of industrial environmental performance began as a response to achieve compliance with legislation (i.e. the Clean Water Act and Clean Air Act) created during the environmental movement of the 1960s and 1970s. More recently, several industries have evolved to view environmental considerations as an opportunity to critically re-evaluate material flows, energy and water use, and product or process design in order to improve efficiency and bolster company performance.

As a result, an entirely new academic discipline has emerged – industrial ecology. Central tenets of the new field include design for the environment (DfE), life-cycle analysis (LCA), and dematerialization, which, when considered in aggregate, describe business as an independent organism possessing "industrial metabolism" (Graedel 1995). Understanding the nature of a facility's input and output streams along all phases of the product/process life-cycle (from resource extraction to end-of-life) can provide a competitive advantage to companies in the form of technological innovation, reduced waste disposal costs, and product differentiation.

The EIP concept represents the fullest application of industrial ecology principles. EIPs incorporate multiple businesses on the same industrial site (or on separate sites, but inter-linked as a "virtual EIP") in order to facilitate synergistic relationships for resource streams. The EIP "mirrors natural systems" in that the waste of one process serves as another facility's raw materials (Cohen-Rosenthal *et al.* 1996). Water, energy, and general overhead costs are shared among participants. Even environmental permitting can be coordinated to some extent via "umbrella" permits granted to the operations of the EIP as a whole (Cohen-Rosenthal *et al.* 1996).

Connecticut Newsprint Company Profile

Connecticut Newsprint, LLC plans to build a 100% recycled newsprint manufacturing facility, which is scheduled to begin operation in the fourth quarter of 1999. Tentatively, the plant will be constructed on a 50-acre site in Bridgeport, Connecticut, although other sites are being considered.[1] James L. Austin, President and Chief Executive Officer, leads the development plans for the company and coordinates a consortium of both private sector and government entities, each of which contributes to the design, construction, or financing of the project. The Development Team includes:

- City of Bridgeport
- Raytheon Engineers and Constructors
- Bridgeport Port Authority
- State of Connecticut
- Office of Policy and Management
- Connecticut Development Authority
- Carpenter Technology
- Papierfabrik Palm
- Thompson Avant International
- Environmental Risk Limited
- Wright Investor Services, Inc.
- Mid-Atlantic Development Corporation
- Hayne and Curley
- Pullman & Comley, LLC
- Frankel and Thornberry
- People's Bank
- United Illuminating Corpation
- Logistec, Inc.

Raytheon Engineers and Constructors, Inc. leads the design and equipment procurement aspects of the project. Financing is provided by multiple sources, including the State of Connecticut, which has approved a $500,000 economic development grant for the project. Bond financing will be provided by Morgan Stanley and Co., Inc. and Greenwich Partners, LLC. Altogether, the Connecticut Newsprint project involves approximately $380 million in capital costs and another $70 million in soft-cost financing.

[1] The location of other candidate sites is proprietary information and cannot be discussed at this time. It is worth noting, however, that other sites possess significant advantages for the long-term scenario proposed in the present study. Among other benefits, these sites are significantly larger in acreage, allowing for potential on-site facilities expansion to include factories manufacturing products that utilize the newsprint plant's sludge as a raw material. Due to the uncertainty involved in the location of the site, a discussion of specific modes of transportation, site conditions, and site layout are generally avoided in the current analysis.

In keeping with being an environmental company in its overall product focus, the proposed Connecticut Newsprint facility will use approximately one-half the energy of a conventional newsprint plant. Moreover, the recycled newsprint manufacturing facility will have a significantly reduced waste stream relative to virgin newsprint plants because the primary source of solid waste from conventional plants is the de-barker (Springer 1994). Another important environmental consideration is the product life-cycle. Having a "lifespan" of only twenty-four hours, a newspaper can potentially be recycled back into the production process in a short period of time (see section on Long-Term Development Plan).

It is estimated that Connecticut Newsprint will have the capacity to process 725 metric tons of raw materials per day. Raw materials consist of approximately 60% old newsprint (ONP), 30% old magazines (OMP), and 10% telephone directories. The raw materials are processed into approximately 630 metric tons per day of high-quality newsprint. At this production level, Connecticut Newsprint aspires to provide 8% of the annual demand in the newspaper-hungry markets of New England and the mid-Atlantic states. Another significant output from the production process is the focus of our analysis – 250 metric tons of short-fiber sludge per day.

Connecticut Newsprint Sludge Characteristics

The process of re-pulping the raw materials includes a de-inking and screening stage (see Figures 1 and 2) from which there is an estimated 15% yield loss in the form of short fibers. This equates to nearly 250 metric tons per day of inorganic sludge as a byproduct of newsprint recycling. The sludge itself consists of short fibers, filler (clay and ash), and inks, which are unusable and therefore removed in the production process. Connecticut Newsprint anticipates that the sludge will exhibit the general physical and chemical composition displayed in Table 1 below.

Table 1 Typical Newsprint/Magazine De-inking Sludge

MATERIAL	COMPOSITION
Ash, dry basis	20–30%
Heat value	5000–6000 BTU/oven-dry lb
Calcium	5000–8000 mg/kg
Chloride	10–80 mg/kg
Chromium	0–12 total, mg/kg
Copper	25–200 total, mg/kg
Lead	0–10 total, mg/kg
Magnesium	750–1250 mg/kg
Nickel	5–14 mg/kg
Potassium	200–400 mg/kg
Sodium	1000–1400 mg/kg
Sulfate	150–250 mg/kg
Zinc	20–45 mg/kg
PH	Adjustable

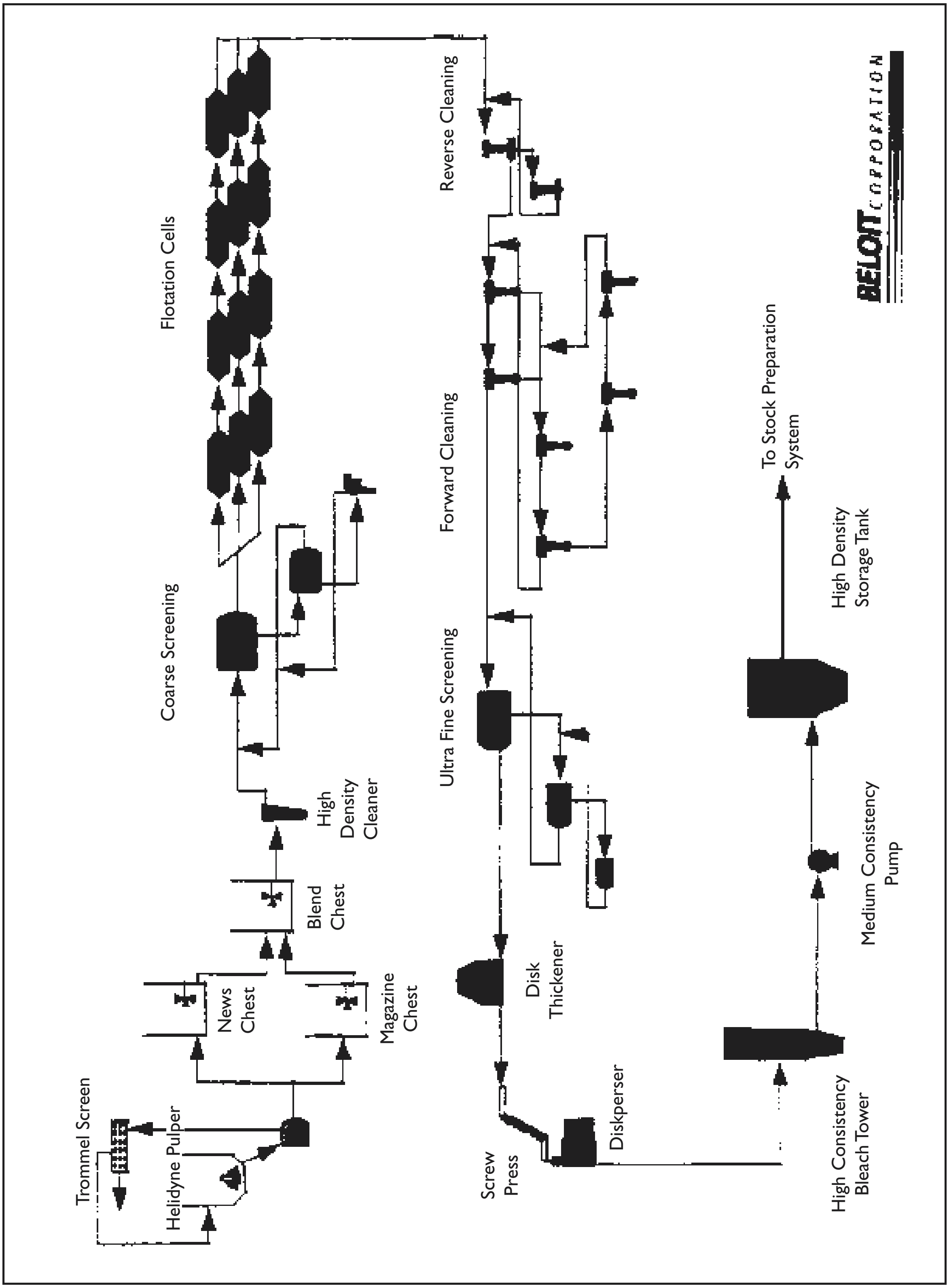

Figure 1 Connecticut Newsprint De-Inking Process System

After passing through screwpresses, the sludge remains 45% solid if further de-watering processes are not applied. As will be discussed in detail later, the composition (especially water content) of the sludge determines its potential uses as a raw material for other products.

POTENTIAL PULP AND PAPER SLUDGE APPLICATIONS

Various applications for pulp and paper sludge are well documented. Among the many potential uses or disposal methods are:

- Landfill disposal
- Landfill clean-capping
- Combustion to generate Btu value
- Composting
- Land application as a soil amendment
- Engineered soils for specific uses
- Cat litter
- Construction materials such as bricks or eco-blocks
- Fuel additive to burn with coal-fired power plants to reduce NOx
- Linerboard feedstock
- Lightweight aggregates

Each of the above options was evaluated in the context of Connecticut Newsprint's particular sludge characteristics. Particularly helpful to our analysis was the Beneficial Use Technologies matrix created by BES Technologies (see Table 2). This matrix evaluates the viability of various beneficial use options based upon solid content. From the suite of choices, our group has selected several viable alternatives for sludge disposal, beginning with those most appropriate for the short-term.

ANALYSIS OF SLUDGE APPLICATION OPTIONS

We employed three primary criteria in evaluating Connecticut Newsprint's alternatives for sludge disposal: 1) sludge characteristics, 2) on-site sludge processing requirements, and 3) transportation costs. Based on these criteria, we analyzed each option to determine the most economically efficient and environmentally friendly utilizations for the byproduct.

The characteristics of sludge include its composition as well as its physical state. The presence of trace metals varies, depending on the particular raw materials used in production. Magazines printed using chemical-based inks produce more potentially harmful residuals than magazines made using a soy-based ink product. Similarly, ash, fiber, and clay content all vary according to the specific inputs. Perhaps most important to our analysis of disposal options is that the solid content of a specific sludge depends on the type of de-watering technology employed in the manufacturing process. Whereas composition may be the sludge characteristic most relevant to environmental concerns, the physical state of the sludge (i.e. percentage of water content) relates more closely to economic considerations.

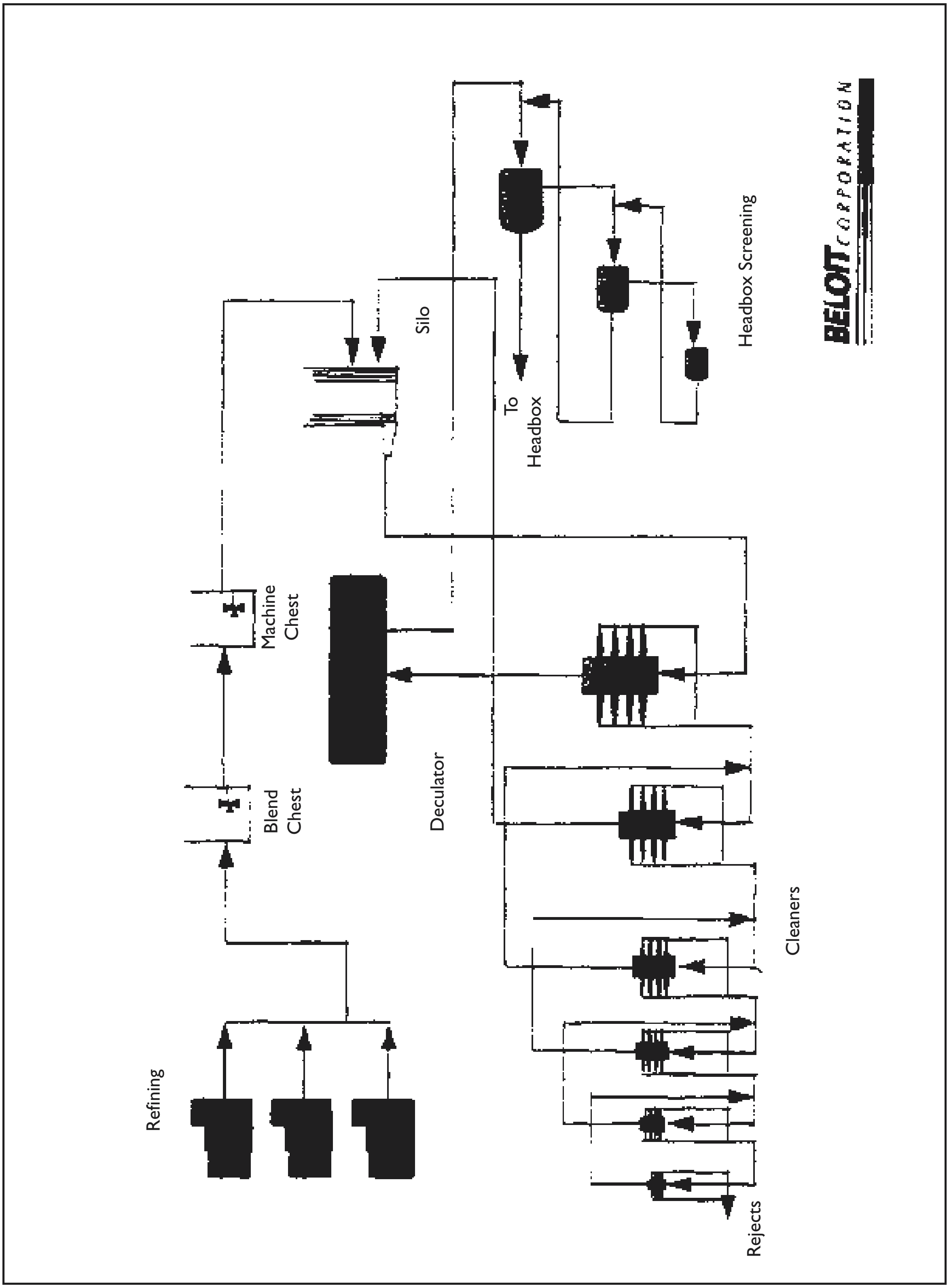

Figure 2 Connecticut Newsprint Stock Preparation System

Table 2 BES Technologies Beneficial Use Matrix

Beneficial Uses	Low Solid Content 0.5 – 24%	Medium Low Solid Content 25 – 39%	Medium Solid Content 40 – 59%	Medium-High Solid Content 60 – 75%	High Solid Content 76 – 100%
Land Spreading	Minimum*	Target**			
Mine Land Reclamation	Minimum	Target	Maximum***		
Landfill Daily Cover		Minimum	Target		
Hydroseeding	Minimum		Maximum		
Clay Cap (as is)		Minimum	Target	Maximum	
Engineered Soil		Minimum	Target		
Compost/Mulch		Minimum		Target	
Animal Bedding & Agricultural Products		Minimum		Target	Maximum***
Absorbents		Minimum			Target
Clay Recovery for Capping			Minimum		Target
Cements & Binders			Minimum		Target
Lightweight Aggregate			Minimum		Target
Molded Fiber & Construction		Minimum			Target
Clay Recovery, Bleaching & Reuse			Minimum		Target
Chemical Products		Minimum			
Fuel & Gasification			Minimum		Target

Each disposal option requires a different level of sludge processing. For example, sludge which is used as landfill daily cover can be shipped to the landfill as is, where it can be immediately applied without further treatment (BES Technologies 1995). On the other hand, the use of sludge as compost material often requires the addition of significant amounts of nitrogen, or even microbial agents (EarthCare website). However, processing does not necessarily need to be completed by Connecticut Newsprint prior to shipping, since many companies that use sludge as an input for their product will buy unprocessed sludge and bear the cost of processing it themselves (BES Technologies 1995).

Once the sludge characteristics and processing requirements are determined, economic factors need to be considered. Foremost among these are transportation costs, which often account for a majority of total disposal costs.

Depending on the location of the plant, the sludge may be shipped by truck, rail, or barge, with each mode of transportation entailing distinct cost advantages relative to site selection. Given these considerations, company President James Austin prefers that short-term sludge disposal operations (of the facility's current 45% solid sludge) occur within roughly a 100 mile radius of Connecticut Newsprint.

Short-Term Scenario

For the short term (during the first 2-3 years of plant operation), our primary consideration was to determine a sludge use which would have low transportation costs and would not require significant on-site processing. We recommend the consideration of two beneficial sludge uses: 1) as a soil amendment (land application) and 2) as landfill capping material.

Land Application

Land application entails spreading or disking sludge over agricultural lands. Pope & Talbot, Inc., of Eau Claire, Wisconsin, has experimented with land application of de-inked sludge for several years, having spread its sludge over 5,000 acres of farmland since 1987 (Cardwell 1994). The Wisconsin Department of Natural Resources permits the company to spread sludge over 800 acres per year, but not to spread repeatedly on the same fields. Because this technology is still in its trial stage, sludge application is limited to acreage planted with cash crops such as field corn, soybean, and hay – not fields which are used to grow crops that will be directly consumed by humans (Cardwell 1994). Despite these regulatory limitations, Pope & Talbot was able to land spread 42,900 wet tons of sludge in 1993 (approximately 200 tons per day based on a 225 day growing season).

The most beneficial aspect of the program from Pope & Talbot's perspective is the realized saving in disposal costs. Traditional landfill disposal costs approximately $45 per ton. Alternatively, Pope & Talbot spends only $4-5 per ton to haul and spread the sludge onto farmland. This difference equates to a savings of over $1.5 million annually.

We believe that Pope & Talbot has set a standard which Connecticut Newsprint can mimic to reduce its own sludge disposal costs. The sludge produced by both companies is similar – each is approximately 45% solid and has substantial fiber content. According to BES Technologies, the target solid content for land spreading is 25-39%; therefore, Connecticut Newsprint sludge represents a close match for this use (see Table 2). Much of central Connecticut is rural, providing ample opportunity for trial applications, and the growing season is similar in length to that of Wisconsin. Moreover, a substantial portion of local cropland is used to grow feedstock or other non-human consumed products (i.e. sod). Extensive studies need to be carried out regarding the long-term effects of the sludge as a soil amendment, but we feel that a short-term alternative similar to that demonstrated by Pope & Talbot should be considered.

Landfill Capping Material

The potential use of sludge as a landfill capping material has recently been explored. While direct application is often allowed, physical and chemical processing is sometimes necessary to gain required capping material characteristics. Technology Development Corporation (TDC) of Fairfield, Ohio, holds patents for a process which converts paper mill wastes containing ash into clays for recovery and reuse. Generally, the process requires 45-50% solid content and at least a 20% ash content (BES Technologies 1995). Its product is then sold to private and municipal landfills as capping material. Due to the potential market which exists in the northeast, TDC is exploring the possibility of building a regional plant in New York State, which would handle up to 750 wet tons of sludge per day. Connecticut Newsprint's byproduct fits TDC's ash and solid content requirements, and could potentially supply approximately one-third of the processing plant's daily demand.

As suggested earlier, sludge is often sold directly to a landfill operator. According to the BES matrix (see Table 2), the suggested solids content for clay capping (as is) is 40-59%, so Connecticut Newsprint falls within the target range. Connecticut Newsprint has arranged preliminary agreements with municipalities in Connecticut and Pennsylvania regarding the use of its sludge in landfill closure projects. However, the costs for use as capping material can often approach those for landfilling itself. Quotes from the two municipalities have averaged $4 million per year for disposal. Therefore, we recommend that Connecticut Newsprint employ landfill capping as a last resort in the short-term.

Medium-Term Scenario

For the medium-term, we took into consideration the desire to further reduce transportation costs, which are a function of weight (largely determined by water content) and shipping distance. We identified available technologies for further sludge de-watering, with the goal of reducing transportation costs by increasing solid content.

De-watering Technologies

Currently, Connecticut Newsprint plans to employ only screwpresses in their de-watering process, which would yield a 45% solid content sludge. The potential next step would be to add another mechanical de-watering device to the process, namely, a tech drier. This technology costs approximately $4 million and would raise residual solid content to 80%. This would significantly reduce overall transportation costs and would allow for alternative disposal options based upon its altered physical state.

If further de-watering is desired, the next step would be to incorporate a fluidized bed boiler into the production process. This technology incinerates the sludge, reducing it to 100% ash content. Employing this technology provides several advantages, namely that the incineration generates a heat value of approximately 5000 Btu per oven-dry pound (see Table 1). A fluidized bed boiler would also produce 30-40% of the plant's steam demand of 250,000 pounds per hour, reducing the need for outside energy sources. However, this technology also possesses disadvantages, namely the $10 million capital costs. Moreover, the on-site incineration process may elicit public discontent as a NIMBY (Not In My BackYard) issue. If either of these technologies are installed, the water content of the residual material will change and a new suite of medium-term options will arise.

Sludge Composting

In the Connecticut Newsprint context, composting could involve the mixing of inorganic sludge with a variety of organic wastes, including municipal sludges and food and fish processing waste. Resource Conservation Services (RCS), a small company in Maine, has worked with several de-inking mills in New York and Maine over the past several years to develop marketable compost products (*Recycled Paper News* 1992). The products have been sold primarily for commercial use, including roadside re-vegetation projects, golf courses, and commercial landscaping. Although RCS has not experienced any incidents of heavy metal or PCB contamination when using the sludge, they maintain a strict policy of not selling their product for agriculture or home vegetable garden applications. Many smaller companies exist in the market, such as Grow-Rich, in Niagara Falls, Ontario, but their low production volumes often restrict them to selling only to local horticultural markets.

We recommend the exploration of composting as a strategy for local disposal. When adjusted by the addition of a tech drier, Connecticut Newsprint's sludge solid content would approach 80%, which closely corresponds to BES's target window of 60-75% (see Table 2). We have identified firms in New York, New Hampshire, and Connecticut, which specialize in marketing sludge-based compost (see Appendix). Because the facility's daily sludge output likely exceeds any small composting company's daily input requirements, we have explored additional on-site composting options.

Building and Construction Materials

Another option for our de-watered sludge is its use as building and construction materials. The use of fibers in cementious products is not a new concept in the paper industry. Scott and Smith (1995) state that sludge use in cementious products generally improves physical characteristics such as plasticity and workability. Tiles containing 13% high-ash sludge possess the required durability needed for commercial use. Similarly, sludge with a 20-30% ash content may be used to produce a commercial facing brick. The advantages of these bricks include better compression rates and increased water permeability. Based on preliminary experimental results, Thomas *et al.* (1987) concluded that a marketable composite material (potentially useful in building blocks, wallboards, panels, shingles, and fire retardant and filler materials for fireproof

Another option for our de-watered sludge is its use as building and construction materials. Scott and Smith (1995) state that sludge use in cementious products generally improves physical characteristics such as plasticity and workability.

doors) could be produced by combining Portland cement with sludge from de-inking mills.

One facet of building materials fabrication involves the formation of aggregates. An aggregate is a collection of materials used as filler in construction products, such as concrete, building blocks, and asphalt (NCASI 1993). Lightweight aggregates (LWA) are a specific subsection of these materials that are used to make composites with increased strength properties and reduced density (NCASI 1993). The use of paper sludge in the production of aggregates has not been well documented, but recent technological and entrepreneurial innovations allow for increased incorporation of paper-based sludges into the building materials industry.

Greengrove Corporation and the Natural Resources Research Institute (NRRI) have explored the use of paper sludge and ash in the formation of a lightweight aggregate through a proprietary mixing process named Agrecell™ (see Figure 3). Greengrove states that the paper sludge component alone does not contain enough fusible material to form the strong ceramic pellets which are necessary for the LWA. However, when mixed with the ash component, the compound exhibits sufficient strength properties (NCASI 1993).

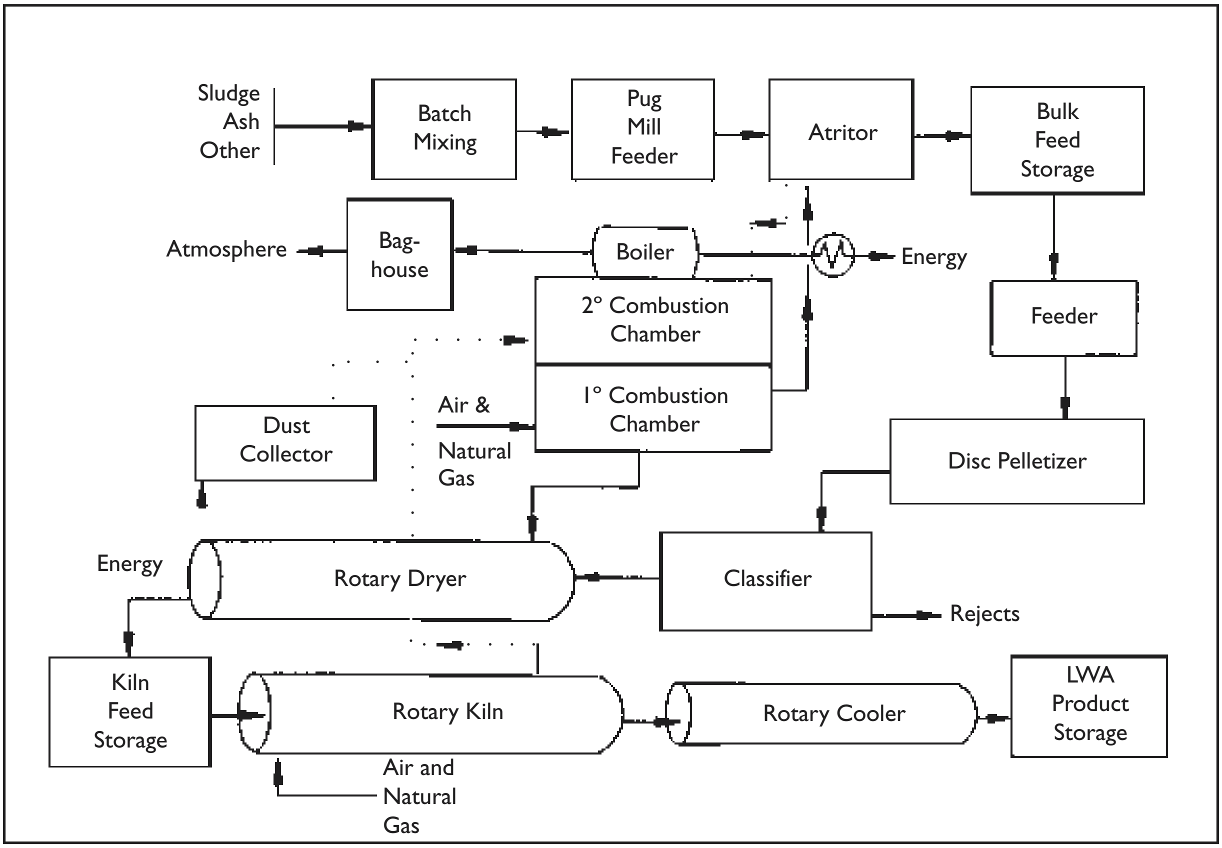

Figure 3 Agrecell Process for Lightweight Aggregate

A pilot-scale production of 20 tons of LWA was completed and test marketed. After receiving encouraging results from the field evaluation, the company planned construction of a new plant in Kaukauna, Wisconsin that would produce 250 tons of LWA per day from 700 wet tons of paper mill sludge and 125 tons of ash per day (NCASI 1993).

Reusable Resources, Inc. developed a different process that thermally treats paper mill sludge to produce an aggregate that can be used as filler in asphalt, roadbeds, cement blocks, and also as a feedstock to cement kilns. The process has been pilot-tested at a site in Middletown, Ohio (NCASI 1993).

Yet another use for sludge in the construction materials industry is the production of eco-blocks. The Paper Science and Engineering Department at Miami University in Ohio is conducting experimental work which entails compressing the short-fibers from newsprint sludge into wood-like blocks to be used for construction purposes. Initial experiments show that newsprint sludge is a suitable substitute for common industrial sludge and therefore could be used in the production of eco-blocks (Miller *et al.* 1997).

Assuming that Connecticut Newsprint employs additional de-watering technologies, the ideal 76-100% solid content desired for building and construction materials will be achieved. With a rapidly growing market for sludge-based construction materials, Connecticut Newsprint should have little difficulty forming business partnerships (see Appendix for a listing of possible companies). Additionally, the reduced water content of the sludge will foster the opportunity to develop relationships with more distant companies since overall transportation costs will decrease.

Engineered Soils

Another means of utilizing Connecticut Newsprint sludge is selling it as feedstock to soil engineering firms. One company, N-Viro International Corporation, incorporates wastewater sludge into its formulation of N-Viro Soil™, which is used as a agricultural liming agent and as a soil blend component (N-Viro International Corporation website). The firm treats and augments the sludge, tailoring the end-product to the specific consumer need. Although N-Viro Soil is not made using newsprint sludge as a raw material, its success in the market as a sludge-based product provides optimism for the prospects of engineering soils from Connecticut Newsprint byproducts.

An example of a company which specifically uses newsprint sludge is BFI, Inc., which employs a proprietary blending technology to manufacture BioMix™. This product is sold as engineered topsoil and is used in projects such as mine reclamation and capping, landfill closure, roadside construction, and sports field improvements. BFI was contracted in 1991 to offer alternative sludge disposal solutions to American Fiber Resources (AFR), which operated a recycled paper plant in West Virginia ("Recycling Paper..." 1996). AFR's byproduct is similar in content to Connecticut Newsprint's 45% solid sludge, suggesting the possibility that a similar resource exchange could take place between BFI and Connecticut Newsprint.

Based on these examples and the aforementioned reduced transportation costs, an opportunity exists for Connecticut Newsprint to develop industrial synergies with soil engineering firms. The marketability of the short-fiber sludge for this growing technology is, again, contingent upon the percent solid content of the byproduct. The BES matrix indicates that the target solid content ranges from 40-59% for sludge to be used as engineered soil. Therefore, this alternative will best suit Connecticut Newsprint in the medium-term (along with the continuation of short-term alternatives) should it decide not to invest in the de-watering technologies previously described. Moreover, this additional alternative enables Connecticut Newsprint to further diversify its sludge disposal options as markets for each technology develop uniquely over time.

Long-Term Scenario

As we move from medium to long-term recommendations, our focus shifts from eco-industrial material flows toward our ultimate goal of an EIP. The concept of bringing raw material suppliers, manufacturers, and consumers together is based on a more efficient use of resources. The plan includes the expansion of operations to include on-site sludge utilization facilities, the attraction of a newspaper publisher to the site, and the development of an on-site raw material recovery center. The details of our long-term scenario are described below as part of our vision of a development plan.

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LONG-TERM DEVELOPMENT PLAN

The future of Connecticut Newsprint is very promising, both ecologically and economically speaking. Part of our environmental strategy involves viewing the firm from an evolutionary and incremental perspective, each step building upon the suggestions put forth in the short and medium-term scenarios. The long-term scenario can be further subdivided into stages of growth that allow the incorporation of EIP principles. Our analysis culminates in the development of an EIP with the newsprint facility as its hub. The opportunity to form a virtual EIP is viable as well, given the local market for resource exchange. The first phase of our long-term development plan involves the development/ recruitment of sludge-utilizing industries to our site.

On-Site Sludge Utilization

The on-site utilization of sludge will be vital to our long-term scenario. Making use of the sludge on-site will facilitate the management of approximately 250 metric tons of the short-fiber sludge per day. This will reduce the total amount of the byproduct needed to be handled off-site, and therefore decrease the cost of transporting the sludge. The following list of suggestions is by no means exhaustive; however, based upon our sludge use matrix and the physical and chemical attributes of the newsprint sludge, these three processes seem to be the most viable options for Connecticut Newsprint:

- installation of cement products equipment (building materials fabrication);
- on-site composting;
- development of a soil engineering program.

Two of the options (building materials and composting) can be incorporated into the newsprint production process under the currently planned design, while the other option (engineered soils) would likely require some additional infrastructure development.

Building Materials Fabrication

Given that many alternatives within the building materials industry are still in the experimental stage, our recommendation is to research further the incorporation of cake sludge processing (CSP) equipment into the Connecticut Newsprint production process (see Figures 4 and 5). We have found one such company that sells CSP machinery to businesses. CemenTech, Inc. offers a CSP series that is designed to accurately proportion and blend waste-water cake sludge (ranging from 12% – 40% solid content) with a combination of alkaline materials at output rates from 5–50 tons per hour of total mixed material (CemenTech website).

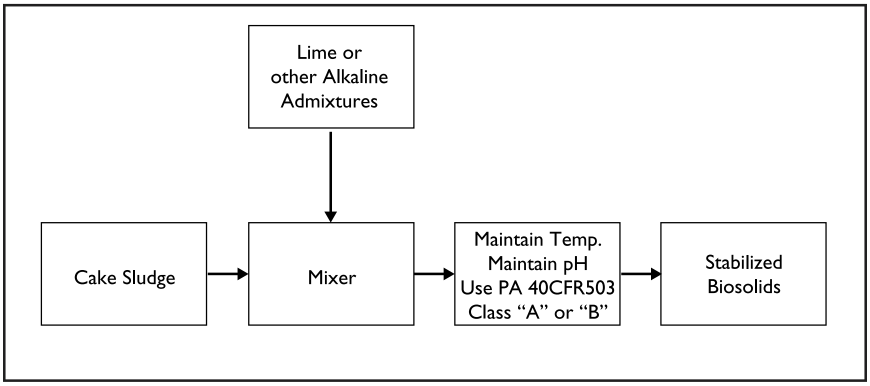

Figure 4 CemenTech Sludge Process Flow Chart

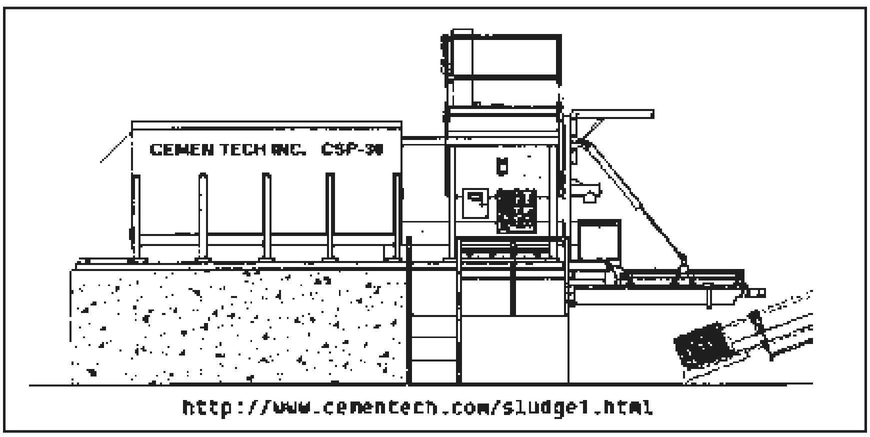

Figure 5 CemenTech Equipment

The company reports that the output material readily meets U.S. EPA Class A or Class B standards. In addition, most of the biosolids processed by CemenTech CSPs are sold to the public. The process includes de-watering the sludge and then loading it into the CSP or holding bin using a conveyor or endloader (CemenTech website). CemenTech has installed CSP equipment in over 25 locations worldwide, providing several examples of functioning systems that Connecticut Newsprint could use as a model for its own CSP installation.

On-Site Sludge Composting

Depending on the final site location selected for the Connecticut Newsprint operation, the potential market for selling compost as an agricultural fertilizer is significant. It is likely that only a small fraction of the 250 metric tons of daily sludge output could be channeled to on-site composting. One simple way to introduce organic material into the composting waste stream is to encourage company employees to dispose of coffee grounds and food wastes along with the sludge for composting. The benefits of applying an explicit composting technology obtained through a company specializing in compost processes (such as EarthCare Technologies, Inc.) is that such companies can provide the following additional services (EarthCare website):

- Analysis of waste streams and methodologies;
- Investigation of suitable areas;
- Production of design specifications;
- Development of infrastructure cost estimates;
- Formulation of operational cost estimates;
- Identification of equipment sources;
- Oversight of site development;
- Acquisition of site permitting;
- Establishment of a compost quality assurance program;
- Production of overall site management plan and operational parameters;
- Implementation of required personnel training programs;
- Operation and management of the site in accordance with the bioremediated, active, thermophilic, windrow composting technology;
- Marketing of the stabilized compost product.

One simple way to introduce organic material into the composting waste stream is to encourage company employees to dispose of coffee grounds and food wastes along with the sludge for composting.

These services can aid in the successful and efficient development of an on-site composting facility. Assuredly, EarthCare Technologies, Inc. is not the only company engaged in this type of operation. Connecticut Newsprint should further survey the array of composting technology companies before selecting a business that will facilitate a sustainable on-site composting program.

Soil Engineering

Recruiting a soil engineering company such as BFI or N-Viro Technologies to the EIP site would allow Connecticut Newsprint to further diversify disposal options. As with the on-site composting program, it is unlikely that the entire 250 metric tons of sludge produced per day will be needed by a single on-site soil engineering firm. Therefore, we recommend that any off-site soil engineering contracts developed during the medium-term scenario be continued as part of a virtual EIP for the long-term.

On-Site Newspaper Publisher

Old newspapers (ONP) are the second most recycled paper product in the United States. In 1995, more than six out of every ten newspapers in circulation were recovered via municipal or commercial recycling. From the recycled paper stream, approximately 36% of ONP is rechanneled into the production of more newsprint (American Forest and Paper Association website). These statistics accentuate the fact that newspapers have a short product lifespan. Technically, a newspaper has a twenty-four hour product life-cycle; therefore, the product can be readily reintroduced into the input stream of the recycled newsprint firm. Furthermore, the newspaper market continues to grow, with nearly 35 million tons produced on a global basis. Per capita consumption in the United States is approximately 44 kilograms per year. European per capita newspaper consumption exhibits a growth potential of 2% per year based on the current demand for approximately 23 kilograms per year. Moreover, it has been forecasted that Asia will soon become a net importer of newsprint (Norske Skog, Inc. website). These statistics support market entry and the development of an on-site newspaper publisher with potential for product exportation.

Technically, a newspaper has a twenty-four hour product life-cycle; therefore, the product can be readily reintroduced into the input stream of the recycled newsprint firm.

We propose two alternatives for Connecticut Newsprint: 1) develop and construct a printing/publishing firm or 2) recruit an outside printing/publishing firm to co-locate on the Connecticut Newsprint site. Connecticut Newsprint plans to produce approximately 630 tons of high-quality newsprint per day. It is unlikely that the on-site printer could feasibly utilize this large outflow of newsprint by itself; therefore, Connecticut Newsprint would need to maintain outside contracts for delivery of its finished product.

According to a 1993 EPA Cluster Profile on Printing, Publishing, and Allied Industries, there are 7,465 newspaper printing companies in existence, 2,617 of which employ twenty or more people (EPA website). These statistics suggest that it is plausible that there are several candidate printing/publishing companies that could be recruited to co-locate with Connecticut Newsprint. However, there are environmental considerations relating to on-site printing that will be examined more closely in sections below.

The idea of recruiting an on-site newspaper publisher stems from the overarching goals of industrial ecology. The process of examining the entire life-cycle of the product can contribute significantly to overall cost reduction and increased efficiency of the Connecticut Newsprint operation. For instance, co-locating the printer/publisher on-site merges two stages of the product life-cycle process by creating feedback loops between the finished product distribution stage and raw materials extraction stage (see Figure 6). Finished product distribution to an on-site publisher would greatly diminish the total transportation and energy costs associated with delivering the newsprint to an off-site publisher. Moreover, the raw materials "extraction" occurs following a twenty-four hour product life-cycle with a continuous daily turnover. This rapid turnover rate is the impetus for our next evolutionary step – the creation of an on-site raw material recovery facility.

On-Site Raw Material Recovery Facility

The proposed recovery facility would have three broadly defined objectives. The first would be to harness the potential of existing material recovery infrastructure by encouraging community recycling centers to enhance their newspaper recovery programs. The centers also should increase the recovery of magazines, which often are not recognized as recyclable material by the public. Contrary to public perception, magazines are in high demand for the newsprint recycling industry. Flotation technology, a recycling process commonly used in Japan and Europe (and recently introduced in North America), requires that newsprint be combined with coated paper such as that found in old magazines (typically 70% newsprint and 30% coated paper) to produce recycled pulp (Canadian Magazine Publishers Association website). The clay filler used in coated stock enhances product quality in several ways – assisting in the flotation operation, adding opacity and brightness to the recycled product, and strengthening the recycled newsprint (Canadian Magazine Publishers Association website). Given that Connecticut Newsprint employs flotation cells in its de-inking process (see Figure 1), we believe that the quality of its finished product would benefit from continual magazine recovery.

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The Canadian Magazine Publishers Association (CMPA) estimates that North American recycled paper mills could require one to three million tons of coated stock per year by the year 2000. Coated stock is used in a number of products in the U.S.:

- 33.3% is used in magazines
- 24.4% in catalogs
- 20.6% in commercial printers
- 11.9% in inserts/flyers
- 4.6% in books
- 4.2% is used in labels

The CMPA states that even if every magazine in Canada were collected for recycling, only about 35% of the demand for old coated paper required by Canadian newsprint recycling facilities would be met. High demand and low supply have inflated the price of old coated stock. For example, prices increased from $120 to $280 (Canadian dollars) per ton, during a recent six-month period. Current estimates state that only 6–10% of available coated stock is being captured by residential recycling programs (CMPA website). Connecticut Newsprint is uniquely situated to take advantage of its market position as an industry leader if it incorporates a raw material recovery program into its long-term plans.

The second objective of an on-site recovery facility should be to develop additional collection infrastructure. Critical to the success of this recovery effort is the formulation of a sound public relations strategy, which increases consumer awareness regarding magazine recyclability. Our proposed recycling facility would have receptacles for used magazines and newspapers both on site and in the community, modeled after the Salvation Army clothes drop-off bins. Possible locations include transportation hubs such as train stations or bus terminals. The recycling facility should also investigate market incentives (i.e., deposit/refund mechanisms) to promote recycling of magazines and newspapers. Incentives can also be created through community work, such as encouraging schools to compete in assisting community recycling efforts in their respective neighborhoods, with the winning school receiving new equipment, such as computers.

The third objective of the facility should be to attract media attention to plant operations and associated recycling issues. The recycling facility could coordinate some positive, media-related activities like community-based cleanup efforts and educational programs about recycling, perhaps through children's programs that involve teaching about the recycling process and giving tours of the site. A favorable standing within the community will benefit Connecticut Newsprint in the long-run. If Connecticut Newsprint has a positive environmental reputation in the community, major construction at their facility – like the installation of a fluidized bed boiler – would likely be viewed more favorably.

Environmental Considerations for On-Site Sludge Utilization Facilities

In order to present a comprehensive analysis, it is necessary for us to consider the environmental impacts not only of our primary facility, but also of those industries that are on-site in our long-term scenario. Co-location of other industries with Connecticut Newsprint in an eco-industrial park presents numerous additional opportunities for coordination of material flows. Conversely, the assemblage of these industries at one site necessarily entails additional environmental impacts, as each facility recruited to the EIP brings its own set of material flows. The following is a brief description of some anticipated flow impacts.

Several environmental considerations are common to each of the three industries we have proposed for the Connecticut Newsprint EIP. All on-site sludge-utilizing companies will require significant water and energy use. Therefore, the potential exists to minimize redundancy in capital infrastructure associated with these resources. For example, a single water intake system could service the needs of all on-site facilities. It is also possible that

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the industrial wastewater from one plant (i.e., the diluted caustic soda used in the recycled newsprint process) may be useful in the production processes of a second facility, thereby reducing the need to cleanse and filter the water as it leaves each plant.

In addition to the shared environmental considerations, each industry has its own environmental issues because of its particular processes. For example, composting may introduce concerns of groundwater contamination via leaching of residual metals from the de-inking process. Soil engineering may involve the formation and use of chemical intermediates that may create their own waste disposal problems. Bringing a publisher on-site poses many industry-specific environmental concerns, as outlined below (Huth 1997):

- A potential impact arises from the chemical properties of the inks used in the printing process. We would recommend that the publisher employ soy-based inks which will reduce heavy metal concentrations when the newspaper is reclaimed in the raw material input stream.
- When locating an off-site publisher, Connecticut Newsprint should try to recruit newer firms since most of the letterpress equipment still in service is now more than 30 years old. This older equipment may have environmental problems related to energy efficiency, cleaning and maintenance, and adaptability to new improvements (i.e., soy-based inks and keyless inkers).

Additional Recommendations for Infrastructure Expansion

Our recommendations for Connecticut Newsprint and associated industries have been primarily process-related. We propose additional recommendations that focus on the construction of the facilities themselves using design for environment (DfE) principles. Our first suggestion is to encourage the use of recycled building materials (perhaps made of sludge or other industrial byproducts) in the construction of the plants. We also recommend that the new facilities participate in the EPA Energy Star program, which identifies ways to make companies more energy efficient. It is plausible that alternative energy technologies such as solar panels and co-generation plants could improve energy efficiency while enhancing environmental performance. Finally, we concur with Mr. Austin's suggestion that land within the site (contingent upon final site selection) should be set aside as a land preserve.

Long-Term Conceptual Model

In our long-term conceptual model (see Figure 6), we depict the organizational structure of some of the material flows discussed, and hope to achieve the industrial ecologist's ideal in the form of an eco-industrial park centered around Connecticut Newsprint. In its most complete form, the EIP would attempt to close the energy and waste loops associated with the newsprint facility and its peripheral industries. This creates a cyclical and complex web of interactions between the various EIP components.[2]

[2] Not all material flows are depicted in our conceptual model due to uncertainty regarding certain feedback loops stemming from the peripheral industries. In addition, quantities are largely omitted from the diagram due to forecasting uncertainties. Common environmental considerations such as shared water and energy resources are also left out of the model.

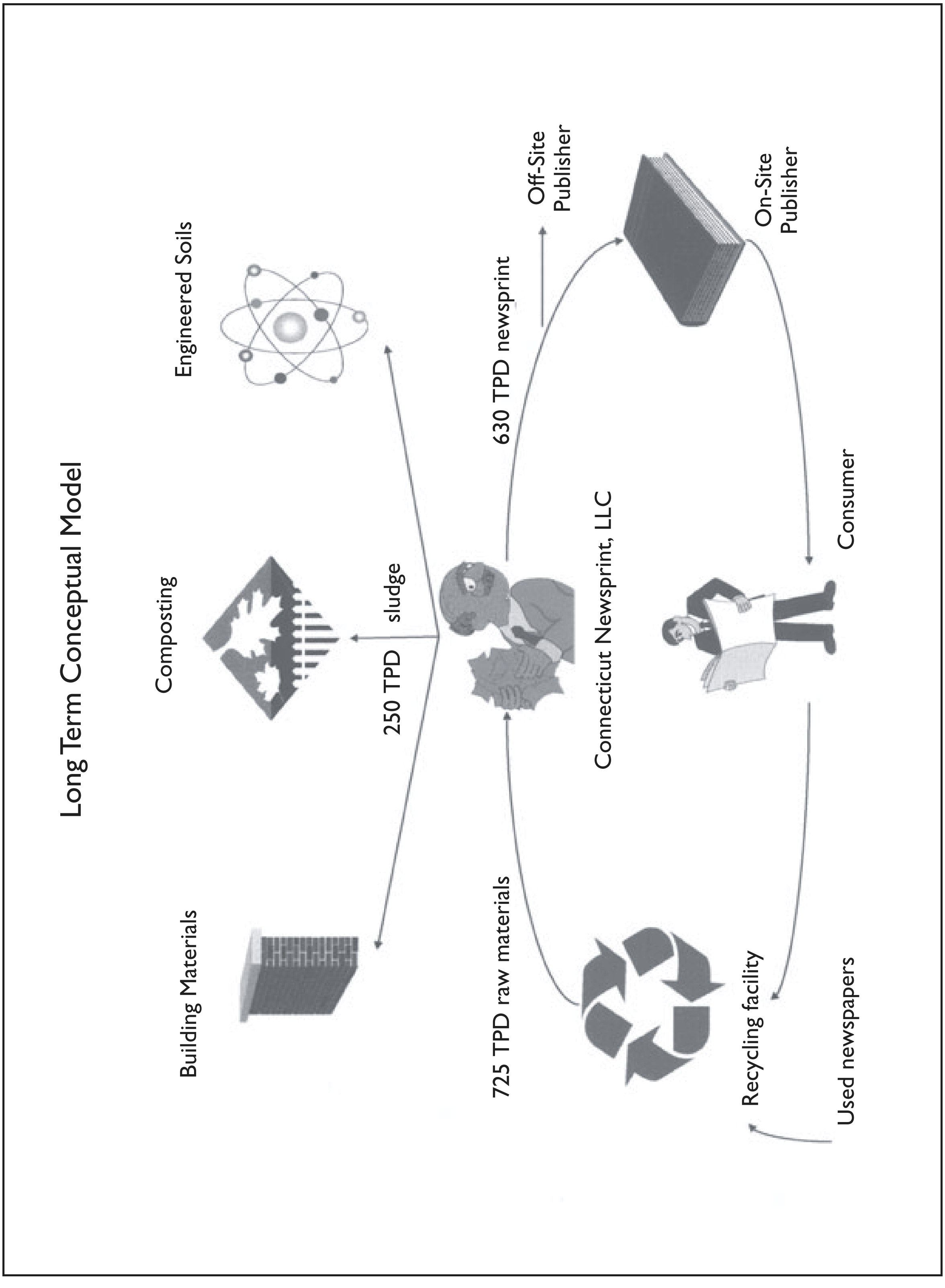

Figure 6 Long-Term Conceptual Model

Reviewing the series of material flows, we begin with the input of 725 metric tons of raw material per day (ONP, OMP, and telephone directories) coming into Connecticut Newsprint from the recycling stream. Connecticut Newsprint then processes this raw material into 630 metric tons of high-quality newsprint per day. This product will then be transformed into printed newspapers and magazines by means of the on-site publisher. As mentioned previously, it is likely that our on-site publisher will not be able to handle the entire 630 metric tons of newsprint on a daily basis (which is contingent upon circulation and newsprint demand); therefore, a portion will be transported to off-site publishers. All publishers (both on and off-site) distribute the finished product to the consumer, who will (ideally) return the used products to our recycling bins facilitated by our recovery program. These steps will close the loop between the product end-life and raw material extraction phases. In addition, Connecticut Newsprint must explore marketable uses for its newsprint sludge. The anticipated 250 metric tons of sludge per day will be distributed among the three aforementioned on-site processes – construction and building materials, composting, and soil engineering.

The gamut of recommendations we have offered in this analysis must be qualified by saying that the sludge technology field is young and evolving. Our suggestions are therefore based upon currently available literature and the general concepts of industrial ecology rather than on actual market feasibility studies (e.g. present value analysis).

ACKNOWLEDGEMENTS

We would like to thank Connecticut Newsprint CEO Jim Austin for the opportunity to work with Connecticut Newsprint and for his willingness to explain the finer details of the recycled newsprint industry. In addition, we thank Jim Lewyta of Hydrofuser Technologies, Inc. for providing substantial materials pertinent to our research.

REFERENCES

American Forest and Paper Association. website. http://www.afandpa.org

BES Technologies. 1995. Beneficial Uses of Paper Mill Residuals for New York State's Recycled Paper Mills.

Canadian Magazine Publishers Association website. http://wwwcmpa.ca/magwaste2.html

Cardwell, M. 1994. Utilizing De-inking Sludge – From Mill to Soil. *Biocycle*. March.

CemenTech, Inc. website. http://www.cementech.com

Cohen-Rosenthal, E., T. Gilliard, and M. Bell. 1996. *Designing Eco-Industrial Parks: The North American Experience*. Ithaca, New York: Cornell Center for the Environment.

EarthCare Technologies, Inc. website. http://www.ecticompost.com

Environmental Protection Agency (EPA). Cluster Profile website. http://www.epa.gov/opptintr/dre/printing/usecluster.html

Graedel, T.E. and B.R. Allenby. 1995. *Industrial Ecology*. Simon & Schuster, New Jersey.

Greengrove Corporation. April 1993. Corporate Literature. Brooklyn Park, Minnesota.

Huth, M.H. September 1997. Newsprint from the Perspective of a Press Manufacturer. *TAPPI Journal* 80(9).
Miller, A. *et al.* October 1997. Eco-blocks from Pulp and Paper Mill Sludge. *TAPPI Journal* 80 (16).
NCASI Bulletin. November 1993. Alternative Management of Pulp and Paper Industry and Solid Wastes. No. 655.
Norske Skog, Inc. website. http://www.norske-skog.com
N-Viro International Corporation website. http://www.nviro.com/pages/virosoil.htm
Recycled Paper News. January 1992. Recycled Paper and Sludge. 2(5).
Scott, G.M. and A. Smith. 1995. Sludge Characteristics and Disposal Alternatives for the Pulp and Paper Industry. I*nternational Environmental Conference Proceedings*.
Springer, A.M. Solid Waste Management and Disposal
Technical Association of the Pulp and Paper Industry (TAPPI) website. http://www.tappi.org.
Thomas, C.O., R.C. Thomas, K.C. Hover. February 1987. Wastepaper Fibers in Cementious Composites. *Journal of Environmental Engineering* 113 (1): 16-31.

FUTHER INFORMATION

Ehrenfeld, J.R. and N. Gertler. 1997. Industrial Ecology in Practice: the Evolution of Interdependence at Kalundborg. *Journal of Industrial Ecology* 1(1): 67-79.
United States Forest Service. Forest Products Resource Laboratory website. http://www.fpl.fs.fed.us

APPENDIX

BENEFICIAL USE TECHNOLOGY COMPANIES

APPLICATION/TECHNOLOGY	COMPANY NAME	CITY/STATE
Agricultural Products	GranTech-Granular Technologies	Green Bay, WI
Cement/Aggregate Products	Greengrove Corporation	Brooklyn Park, MN
Cement/Aggregate Products	Minergy Corp (Sub Wise Energy)	Milwaukee, WI
Cementious Products	Advanced Concrete Technologies	Portsmouth, NH
Cementious Products	Enviro Block Industries	Indian Harbor. Beach, FL
Cementious Products	Systech Environmental Corp.	Xenia, OH
Cementious Products	TDC (Technology Development Co.)	Fairfield, OH
Chemical Products	Biofine Incorporated	Wellesley, MA
Compost	AllGro (Sub Wheelabrator Co.)	Hampton, NH
Compost	Earth Blends	Jordan, NY
Compost	International Process System	Glastonbury, CT
Compost	SSI (Sludge Systems Int'l)	Eau Claire, WI
Compost	The Scotts Company	Marysville, OH
Compost	Wilmot Farms	Buskirk, NY
Dewatering Equipment	Andritz-Ruther	Arlington, TX
Dewatering Equipment	Castine Energy Services	Waterville, ME
Dewatering Equipment	Enviro Tech Systems Corporation	Vancouver, BC (Canada)
Dewatering Equipment	Hydropress	Hatfield, MA
Dewatering Equipment	IMS (Innovative Material System)	Olathe, KA
Dewatering Equipment	Mobile Dredging & Pumping Co.	Chester, PA
Dewatering Equipment	UES (Upstate Environ Services)	Syracuse, NY
Dewatering & Separation	ZSB (Zane S. Blanchard & Co.)	Hampton Beach, NH
Dewatering-Drying Equipment	Baker-Rullman Mfg., Inc.	Watertown, WI
Dewatering-Drying Equipment	DUPPS Corporation	Germantown, OH
Dewatering-Drying Equipment	Stord, Inc. (An Aker Company)	Greensboro, NH
Dewatering-Separation	AFTEC (Applied Filtration Tech.)	Rochester, NY
Drying Equipment	Aeroglide Corporation	Raleigh, NC
Drying Equipment	Consertherm Systems Inc.	South Windsor, CT
Drying Equipment	M-E-C Company	Neodesha, KS
Drying Equipment	Ottawa Valley Grain Products	Renfrew, Ontario (Canada)
Drying Equipment	Rader Companies (Sub Beloit)	Memphis, TN
Drying Equipment	Wal-Dor Industries Ltd.	New Hamburg, Ontario (Canada)
Drying-Absorbent/Animal Bedding	Energy Management Services LP	Solvay, NY
Energy Recovery	EPI (Energy Products of Idaho)	Coeur d'Alene, ID
Energy Recovery	Ichikawa EE Co. Ltd	Ichikawa City (Japan)
Energy Recovery	InnovEnergy Ltd.-Antrim Energy	Marblehead, MA
Energy Recovery	Kubota Corporation of Japan	Japan
Energy Recovery	Tampella Power Inc.	Tampere, Finland
Engineered Soils	Browning-Ferris Industries	Houston, TX
Gasification	Thermogenics, Inc.	Albuquerque, NM
Land Applic. - Compost - Dewatering	Enviro-Gro Technologies	Baltimore, MD
Land Applic./Dewatering	Bio-Nomic Services Inc.	Charlotte, NC
Landfill Cover-Hydroseeding	New Waste Concepts	Perrysburg, OH
Molded Products	Fiber Mold & Petruzzo Products	So. Glens Falls, NY
Molded/Building Products	All Paper Recycling, Inc.	St. Peter, MN
Oil Absorbents	Absorption Corp.	Bellingham, WA
Oil Absorbents	Cellutech, LTD	Deferiet, NY
Pelletizing Equipment	CPM (California Pellet Mill)	Crawfordsville, IN
Pelletizing Equipment	Lundell Manufacturing Co., Inc.	Cherokee, IO
Pelletizing Equipment	Warren-Baerg	Dinuba, CA

Source: BES Technologies

AES -Thames and the Stone Container Corporation: The Montville Eco-Industrial System 1997

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ABSTRACT
Eco-industrial parks (EIPs) have recently appeared as an innovative approach to addressing modern business concerns in the face of increased environmental degradation. From the most complex (Kalundborg) all the way down to two-company linkages, the implementation of this concept is becoming increasingly widespread around the world. The focus of this paper is to illustrate one such linkage in Montville, Connecticut, established by AES Corporation, a global power company, and Stone Container, a major paper company. The first section of this paper will describe the natural environmental and local industrial components of the area to provide some background on the Montville area. Following will be a description of the innovative AES/Stone Container linkage. A section outlining several scenarios for the development of the region within the conceptual framework of eco-industrial activity and a section on policy implications will conclude the paper.

THE TOWN OF MONTVILLE

Town Profile

The town of Montville incorporates the villages of Uncasville, Mohegan, Chesterfield, and Oakdale in southeastern Connecticut. Montville lies west of the Thames River, about 5 miles from Long Island Sound, 2 miles south of Norwich and 1.5 miles north of New London. The town was founded in 1786 and has an approximate population of 16,750 people on 43.9 square miles of land. It is governed under a Mayoral/Town Council system. Montville is mostly rural and suburban, although a number of industrial plants and state and federal installations are located along the Thames River. Upland areas along the river, at one time cultivated, have become overgrown with woods and scrub.

Resources

Sand and gravel, used in the production of concrete, are valuable natural resources in eastern Connecticut. The largest of these glacial deposits are located in the terraces along the Thames River. Clayey till, which compacts well, is used for fill in highway construction. Agriculturally, the land is fertile because of the eolian material (windblown sediment) that covers much of the quadrangle. This material is easily worked, holds water fairly well, and is relatively free of stones. Some swamps in the area have been converted to cranberry bogs and some of the swamp muck has been used as fertilizer for lawns and gardens. Because of the shallow stream gradients in Montville, hydroelectric power cannot be produced. Adequate supplies of water are kept in storage reservoirs and settling basins for industrial use along many of the upland streams. There is also quite an extensive system of springs and wells in the Montville area.

INTRODUCTION TO INDUSTRY IN THE MONTVILLE REGION

Following is a description of some major and minor companies located in the Montville region. These companies will be discussed further in the presentation of three possible scenarios for the establishment of an EIP in the Montville area.

AES Corporation

AES Corporation is a multinational independent power producer. The corporation puts together financing for power plants, has them built by outside contractors and then owns and operates them. AES currently retains primary ownership of 12 plants and has interests in 21 others, located around the world (Salpukas 1997). AES Corporation's mission is to provide clean, safe, low-cost electricity (Cropper 1993). All of their six U.S. plants run on coal and are designed either to meet the needs of independent customers or to serve as supplements to a utility.

AES has a reputation for being among the most environmentally conscientious power producers in the United States. By developing highly specialized, clean coal burning technologies, AES has demonstrated its dedication to minimizing the emissions traditionally associated with coal plants, particularly sulfur and particulate emissions. In addition to carefully monitoring their emissions, the company has a forestation project designed to offset the potential exacerbation of global warming created by the emissions associated with all of the company's power plants. As a result of this effort, over 52 million trees will be planted in Guatemala (AES Corporation 1996).

In addition to being concerned with minimizing emissions, AES is also concerned with minimizing the amount of energy wasted in the electricity-producing process. As a result, six of the U.S.-based AES power plants are cogenerators. A portion of each plant's "waste" steam, is redirected to a local, symbiotic company, to be used in its manufacturing processes.

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Given the maturity of the U.S. electricity market and the general lack of demand for new power plants, AES is focusing approximately 90% of its development efforts on meeting the growing global power needs. While its U.S. plants are mostly coal dependent, due to the large domestic supply of coal and its historically cheap and stable pricing, AES's plants overseas rely on a broader array of fuel sources such as gas, oil, hydro, and coal. Just as coal powered plants are less common abroad, so are the cogeneration plants that AES is renowned for domestically (Bryne 1996).

AES Thames Montville, Connecticut Plant

At its Montville facility, AES Thames produces 181 MW/hour of electricity, which is sold to the neighboring Northeast Utilities plant. The AES plant imports coal from West Virginia. The coal is burned using the aforementioned clean coal technology. At the start of the process, the coal is crushed and mixed with limestone and injected into the boiler (see Figure 1). As the coal burns, the sulfur dioxide is absorbed by the limestone and the ash, and hot gases produced flow to the top of the combustion chamber. These ashes and hot gases flow out

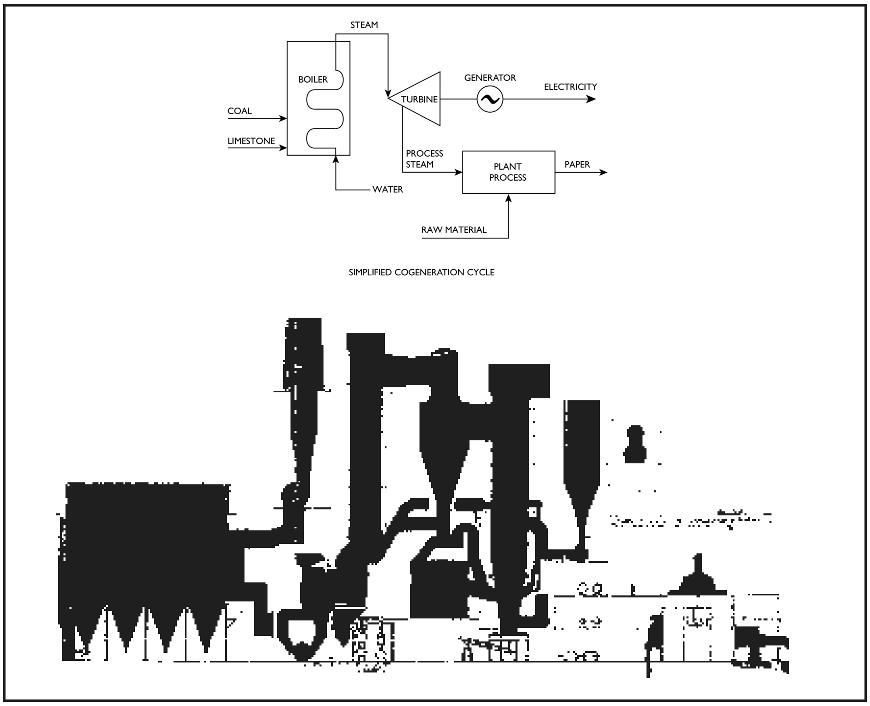

Figure 1 AES Thames Cogeneration Plant

the top of the combustor into the Hot Cyclone. Partially burned fuel and ash are re-injected into the combustor, in order to get maximum fuel efficiency. After full combustion, the hot exhaust passes over banks of water and steam piping in the Convective Pass to produce superheated steam.

Ash taken from the Cyclone heats the final reheated and superheated steam and then returns to the combustor. This superheat steam is then directed to a turbine, which is propelled to produce electricity. The exhaust gas, which by now has lost most of its heat, is routed through fabric-filter baghouses, which remove and collect the particulates and fly ash for disposal.

At the end of the coal burning process, AES is left with several waste products. The remaining fly ash, which is composed of limestone and particulate matter, is typically used as landfill for post-mining applications. AES is also left with non-contact cooling water which has warmed by 17°C before it is returned to the adjoining river. Levels of air emissions associated with electricity production are high, especially sulfur dioxide (SO_2) emissions, and therefore have to be carefully monitored. Some of the excess steam produced is routed as fuel to the Stone Container Corporation's manufacturing processes. However, there still remains steam that could be used for cogeneration.

Stone Container Corporation

Stone Container Corporation (SCC) is a major, multinational paper company with annual sales in excess of $5 billion (authors' note: Stone Container Corporation was recently purchased by Jefferson-Smurfit and renamed Smurfit-Stone). The corporation produces a variety of paper and corrugated cardboard box products as well as pulp for market. At a few facilities SCC also produces lumber and wood chips. SCC operates over 200 facilities in the United States, Europe, Australia, Asia, and Central and South America.

SCC emphasizes environmental, health, and safety issues and places them high on its list of priorities. In its forestry practices, SCC is committed to Best Management Practices (BMPs) on its timber land and it has established the Landowner Assistance Program to help landowners in the southeastern United States learn about them as well.

In the corporation's environmental report, it calculates that approximately one third of the fibers used in its products are from pre-used sources, making SCC, in its estimation, the world's largest consumer of pre-used paper products (SCC 1997).

SCC is committed to environmental stewardship in its plant processes. In the corporation's environmental report, it calculates that approximately one third of the fibers used in its products are from pre-used sources, making SCC, in its estimation, the world's largest consumer of pre-used paper products (SCC 1997). In a joint venture with WMX, the world's largest collector of recycled paper, SCC established PRI, a shipping corporation that supplies recycled materials to SCC and other corporations around the world.

SCC not only uses recycled fiber for its products, but also developed a product take-back policy, collecting its post-use products from customers for recycling. SCC already has 100 closed loops in place and plans to collect over 85 million pounds of old product from its customers in 1997. In addition to using recycled paper products for its manufacturing process, SCC practices on-site cogeneration, reusing boiler steam to produce electricity and to provide heat for the pulp cooking process as well (SCC 1996).

Between 1991 and 1995, SCC affected a 19% corporation wide decrease in energy use, 11% of which was due to a reduction in fossil fuel use. In addition to reducing energy use, SCC is also moving toward a significant reduction in its plants' already low air emissions and has a goal of zero waste-water discharge.

Despite SCC's active environmental programs, a number of grassroots organizations claim that the bottom line is of much greater importance to the company. For example, La Sierra, an environmental action group, professes that Stone Forest Industries, a subsidiary of SCC, is selling timber in Colorado and elsewhere below cost. According to this group, SCC is also currently in violation of anti-pollution laws in fifteen states (Boulder Community Network 1997).

Stone Container Corporation: Montville, Connecticut Plant

SCC's Montville operation produces low-grade corrugated cardboard, which serves as filler for cardboard box walls. This plant uses 100 % recycled materials in its manufacturing processes. When the used paper products arrive on site, they are converted into pulp by a hydropulper. Through a subsequent set of filtering processes, the "waste" materials are removed and the pulp is dried. The pulp is then passed through a refinery, screens, and sand traps, where further impurities are removed. Once cleaned, the pulp is pressed out flat on the fourdrinier to be heat dried. When the process is completed, the cardboard is sold to the Rand Whitney Corporation as a filler for box shells.

Not all of the post-use materials that are imported into the plant by truck and rail to be used in the cardboard production are reusable. SCC is forced to deal with a significant amount of refuse, removed through the filtering process, including plastics, paper, Styrofoam, glass, and baling wire. In total, 25 tons/day of plastics and 15 tons/day of metals are recovered. These materials pose an important problem, as the corporation is unable to recycle much of this waste due to its heterogeneous nature and is currently paying to dispose of it at a landfill.

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Another environmental issue facing the Montville plant is the large amount of water required for the pulping process. Three types of water management problems result from the process: diversion, non-contact cooling water, and storm water discharge. The plant also has to monitor nitrous oxide (NO_X), sulfur dioxide (SO_2) and volatile organic compound (VOC) emissions associated with an on-site boiler that produces some of the energy to fuel operations, although these emissions are generally low.

Dow Chemical Company

The Dow Chemical Company is the fifth largest chemical company in the world. Dow produces plastics, chemicals, agricultural products, and consumer goods, reaping annual sales of more than $20 billion. With close to 40,000 employees and 94 manufacturing sites in 30 countries, Dow is a powerful multinational corporation with a great potential for environmental impact. In 1994 alone, for example, Dow generated over 1,500 tons of global emissions of EPA priority compounds (Dow Chemical Co. 1996).

Dow operates a sizable production plant on the east bank of the Thames River across from AES and Stone Container. Originally built in 1952 to manufacture Styron, the plant has constantly expanded over the last several decades to accommodate Styrofoam, butadiene latex, and Magnum ABS resin production. The energy and raw material inputs were not made available for this study. However, the multi-product facility generates several residual air, water, and solid waste streams. These include acrylic acid, acryloritrile, butadiene, chloroethane, dichlorethane, ethlybenzene, and styrene. In addition, the company operates a solid waste landfill on the site to handle 620 cubic yards of latex residuals annually (Dow Chemical Co. 1995). The landfilling operation includes mixing the latex with soil to speed biodegradation and covering the mixture with grass seed, mulch, fertilizer, and limestone. Although the Dow residuals and operations hold great potential for an area EIP, Jack Tamborra, the government affairs manager for the Northeast region states, “While it appears to be of some academic interest, we as a company are not willing to participate” (Tamborra 1997). Dow has published several pro-environment marketing brochures for programs at the corporate and local level. However, it appears that the company is not interested in eco-industrial park development at the present time. Therefore, we will not consider its potential contribution to the area EIP.

Rand-Whitney Corporation

Rand-Whitney is about 1.5 miles away from AES and Stone Container in Montville. Similar to Stone, it is a cardboard processing plant, producing a finer grade of cardboard box. Rand-Whitney produces the outer cardboard walls for Stone Container products. Its flows are similar, namely cardboard pulp and a lot of water to produce its product. Rand recycles its water from the sewage treatment plant.

Northeast Utilities

Northeast Utilities (NU) owns and operates a 600 MW power plant 1.5 miles from the AES-Thames cogeneration plant. This NU plant operates on oil and natural gas. In addition to its own electricity production, Northeast Utilities has a contract to buy 181 MW from AES.

The Montville Sewage Treatment Plant

The Montville Sewage Treatment Plant is just a few hundred yards away from AES. It treats wastewater for the surrounding area, including the town of Montville, the Mohegan Sun Casino and Rand-Whitney. It has a total budget of $2 million per year, and 11 full time employees.

The plant uses activated biological processes to remove pathogens and break down the sewage it receives. Large electrical-powered turbine blowers are used at this site to aerate the water. The water is then sent through settling tanks to remove the solid waste. The sludge produced is 5% solids, with no heavy metals or other hazardous contaminants. It is sent offsite for further drying and incineration.

Faria Corporation

Faria Corporation is a marine gauge manufacturing company. It processes raw metal using injection molding and stamping to manufacture parts. These parts are then painted in closed and filtered machines and assembled. Faria is a zero discharge facility, which means it has no air or water waste. However, there is a variety of solid waste which is dealt with in various ways. The metal scrap from the stamping process is sold to a local scrap dealer. Paint rags and carbon filters from the painting step are incinerated. Corrugated cardboard from packaging is recycled at Stone Container Corporation. Plastic resins are reground and recycled. Wooden pallets from shipments are sold to a local business that remakes and resells them. Office papers are recycled and all other trash (mostly office waste) is landfilled.

Faria buys its electricity from the grid. The representatives were unable to provide a specific use amount, but indicated that their manufacturing processes are energy intensive. They heat the plant with steam produced on site.

EXISTING CONNECTIONS BETWEEN MONTVILLE INDUSTRIES

Input-Output Flows

Input-output flows were calculated from data provided by Kevin Pearce at AES-Thames, Lou Armstrong at Stone Container, and the Montville Sewage Treatment Plant. Flows were quantified to obtain a better understanding of the exchange of materials in this industrial area. With this knowledge the potential for linkages between industries as well as between flows is examined. All figures were converted into a standard metric (tons per day) for the purposes of comparability and consistency (see Figure 2).

Major waste streams from each of the three industries examined will be discussed briefly here. These are the streams that will be addressed in the three scenarios proposed later in this paper. Stone Container produces a solid waste stream of 25 tons of mixed plastics, which currently is being landfilled. Of these

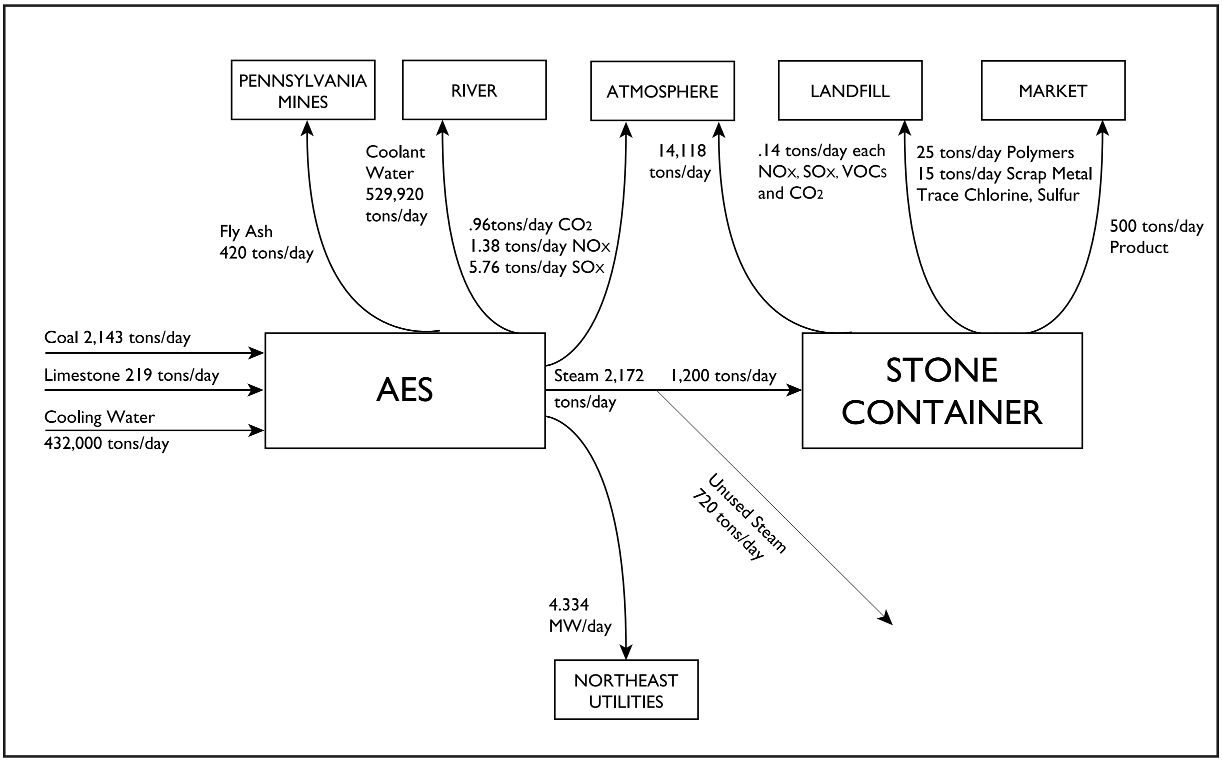

Figure 2 AES-Stone Container Corporation Cogeneration Flow Chart

25 tons of plastic, 20 tons can be used commercially in a variety of different applications. Stone Container also produces approximately 15 tons of scrap metal, glass, Styrofoam, dirt, gravel, and other miscellaneous materials. These materials are also currently being landfilled and are not, at this time, commercially reusable.

AES-Thames, being an electricity producer, generates a large quantity of air emissions including SO_X and NO_X. In addition to these emissions, AES produces approximately 420 tons of coal ash per day. Currently this ash is sent back to coal mines in Pennsylvania for reclamation. Of this 420 tons, 60%, or 252 tons per day, is commercially viable as various forms of fly ash. AES also produces vast quantities of steam. Sixty-five percent of the heat in this steam is lost to the stack and to the Thames River. Twelve hundred tons of steam per day is piped to Stone Container as part of a cogenerative process. The additional heat produced each day is not being utilized; rather it is condensed, then released into the Thames River. Non-contact cooling water flows through the AES plant in extremely large volumes. This water is released into the river at an average rate of approximately 43,200 tons per day.

The Montville Sewage Treatment Plant is a municipal plant that processes sewage waste at a rate of 1,200 tons of input per day. Of this, 60 tons is solid material (sludge) and the additional 1,140 tons per day is treated water. Following are the calculated material flows for Stone Container Corporation, AES, and the sewage treatment plant.

Table 1 Stone Container Material Flows

INPUTS	
Raw Materials	Old Corrugated Cardboard (OCC) = 540 tons/day
Energy	Electricity Needs = 8 MW/hour x 24 hours/day = 192 MW/day
	AES Steam Supplement = 1.5 MW/hour of energy x 24 hours/day = 36 MW/day; 36 MW/day x 10,000 lbs of steam/day = 360,000 lbs of steam/day; 360,000 lbs of steam/ day x 1 ton/2000 lbs = 180 tons/day
OUTPUTS	
Product	OCC = 500 tons/day
Solid Residuals	Mixed Plastics = 25 tons/day; 20 tons of which are recoverable
	Scrap Metal = 15 tons/day; none of which is currently usable
Liquid Residuals	Trace amounts of chlorine and sulfur
	No water waste due to operation as a closed system
Gaseous Residuals – Regulated Amounts	NOx = 0.14 tons/day
	SO_2 = 0.14 tons/day
	VOCs = 0.14 tons/day
	CO = 0.14 tons/day

Table 2 AES-Thames Material Flows

INPUTS	
Raw Materials	Coal = 2,143 tons/day
	Limestone = 219 tons/day
	Non-contact cooling water = 1.08 x 10^8 gallons/day x 8 lbs/gallon x 1 ton/2,000 lbs = 432,000 tons/day
Energy	517 MW/hour based on 35% efficiency of 181 MW/hour x 24 hours/day = 12,408 MW/day
OUTPUTS	
Product	Energy = 181 MW/hour x 24 hours/day = 4,344 MW/day
Solid Residuals	Fly-ash = 420 tons/day
Liquid Residuals	Water (non-contact cooling, etc.) = 1.10 x 10^8 gallons/day x 8 lbs/gallon x 1 ton/2,000 lbs = 440,000 tons/day
	Steam = 10,000 lbs/MW x 4,344 MW/day x 1 ton/2,000 lbs = 21,720 tons/day 14,118 tons/day at 65% efficiency is lost to the stack and to the non-contact cooling water 1,200 tons/day is given to Stone Container 720 tons/day is excess that could potentially be collected
Gaseous Residuals	CO_2 = 0.96 tons/day
	NOx = 1.38 tons/day
	SOx = 5.76 tons/day

Table 3 Montville Sewage Treatment Plant Material Flows

INPUTS	
Sewage	300,000 gallons/day x 8 lbs/gallon x 1 ton/2,000 lbs = 1,200 tons/day
Energy	$20,000/month (@ ~ $0.09/KW-hour)
OUTPUTS	
Solid Residue	5 % of 1,200 tons /day = 60 tons/day
$600,000/year disposal bill	27.4 tons/day incinerated based on $60/ton tipping fee (info from SCC) and a
	32.6 tons/day must be landfilled
Liquid Residues	Treated Water = 1,140 tons/day
Gaseous Residues	None reported

SCENARIOS FOR THE DEVELOPMENT OF AN EIP

This section is dedicated to the group's recommendations as to how the above mentioned materials and energy flows can be improved to increase efficiency. Scenario 1 will focus on improvements that can be made with minimal effort while Scenario 2 will propose more wide-reaching changes. Scenario 3 will propose a more radical solution to the current waste problems facing the industries of the Montville region.

Scenario 1: Improvements on the current system

This first scenario proposes changes that could be made without bringing in or setting up any new business in the area.

Triangulation Improvements

A current practice of Stone Container is triangulation. This involves taking its finished product of cardboard boxes, shipping it to a packing plant for the customer's product, then taking the boxed items and bringing them to the retailer. From the retailer, a truck then picks up the used cardboard and brings it back to the plant to be recycled. This type of system forms an efficient triangle, and could be expanded for the area.

Rand-Whitney and SCC Waste Recycling Improvements

Currently, Rand-Whitney is producing 40 tons/day of Old Corrugated Cardboard (OCC). Due to incineration costs, the OCC is being landfilled since it is $20/ton cheaper to dispose of it in this manner. Rand cannot use this OCC since it is producing the outer sides of cardboard boxes, and appearance and texture count in its final product. However, Stone Container's product (the inside filler of cardboard boxes) is much rougher, and it can potentially use this OCC in its product. This system would be cheap and environmentally efficient, and would benefit both Rand-Whitney and Stone Container. Stone would need to invest in some new machinery to process and clean up the OCC to create a material that it can use.

AES Waste Heat Use Improvements

AES currently has two large volumes of heat that are being lost to the environment: the low-pressure steam that emerges from its turbines, and the cooling water that is deposited in the river (see Table 4).

The current contracted average shows what AES is producing right now. As seen in the table there are 720 tons/day of excess low-pressure steam that are not being utilized. This steam could be used for increased district heating or on-site electricity production. District heating uses a central source to produce steam or hot water that is then pumped to nearby homes and businesses. The AES steam is well within the parameters needed for district heating and could be used for this purpose. Pipes would be necessary to distribute it to the area. There are several businesses in the area that would be good targets for this: Faria, which is already heating with steam produced on the premises, Rand-Whitney,

District heating uses a central source to produce steam or hot water that is then pumped to nearby homes and businesses. The AES steam is well within the parameters needed for district heating and could be used for this purpose.

Table 4 AES Steam Availability

	Current Contracted Average	Current Possible Maximum	Production Possible with Major Renovations
Energy Production (MW/hour)	181	187	200
Total Steam Produced (tons/day)	21,720	22,440	24,000
Potential Excess Steam (tons/day)	720	784	922
Potential Energy (MW/hour)	0.90	0.98	1.15

SCC, the Sewage Treatment Plant, and the Mohegan Sun Casino. The other option for the low-pressure steam is to use it to produce energy at other businesses. The potential energy output from this steam is shown in the last row of Table 4, and ranges from 21.6 MW/day to 23.0 MW/day with the existing set-up. Other local businesses could utilize this potential energy source in the same way as SCC to produce cheap electricity. Potential users would be the Sewage Treatment Plant, Faria, Rand-Whitney, and the Mohegan Sun Casino.

AES Cooling Water Improvements

AES uses approximately 75,000 gal/hr of cooling water. This is equivalent to 820 million BTUs/hour being lost to the river. AES designed the plant under a National Pollution Discharge Elimination System (NPDES) permit that limited the average temperature range of the water discharged to prevent heat pollution to the river. This range is currently 18°C in the summer and 20°C in the winter. This means that the cooling water is not as readily usable as the steam. However, with some changes to the AES cooling system, this could become a very efficient way to produce hot water for district heating. A system designed to use less water, and to recycle it through a closed loop would be very practical for this district heating. Currently, the coolant water is also treated to minimize chlorine pollution. A closed loop would prevent the need for this type of treatment as well.

Scenario 2

The goal of this scenario is to find appropriate uses for the large waste streams produced by these industries. Scenario 2 actively seeks to introduce new industries and technologies and to promote new material linkages. It allows the eco-industrial park relationship to be strengthened while still maintaining a sense of independence and flexibility. By being proactive and testing the frontiers of these particular industries, Scenario 2 may also be able to prohibit the dangerous concept of "lock-in," where if one company fails, the entire system fails. This type of approach is crucial to ensuring the overall success of the EIP in the long term.

Development of Commercial Use of the Coal-Ash Produced by AES

Combustion of coal produces large volumes of waste. One component of this is coal ash, which includes fly ash, bottom ash, flue gas de-sulferization sludge, and fluidized bed combustion wastes. Coal burning plants in the U.S. are producing around 75 million tons of ash annually. Currently, only about 24% of this ash is being utilized, with the remaining amount being landfilled (West Virginia University 1996). Since coal is a nationally produced energy source and prices are relatively stable, coal ash as a waste stream is not likely to be reduced any time in the near future. Due to these large volumes of coal ash, a number of alternatives to landfilling the waste have been devised. These alternatives range from simple applications to complex commercial processes that regard coal-ash as a raw material resource. AES is producing 420 tons of coal ash a day – a huge potential resource.

One of the simplest uses for coal ash is reclaiming the mines from which the coal was originally mined. The ash is alkaline (due to the limestone residue from burning) and so neutralizes the natural acidity of old mine sites. The ash can also increase a plant's available water, reduce the toxicity of trace metals, and allow for better aeration of the soil. Vegetation in mine areas can be maintained for decades on ash-treated soils, where plants have failed on conventionally treated soils (Geonews 1996). AES is currently using its ash to reclaim mine sites in Pennsylvania. However, its contract to ship the ash ends in three years. Other alternatives within the Montville area might prove more economically and environmentally feasible.

Many structural uses for coal ash have been developed. Most use fly ash, which is one of the finer particulates of coal ash. Fly ash comprises approxi-

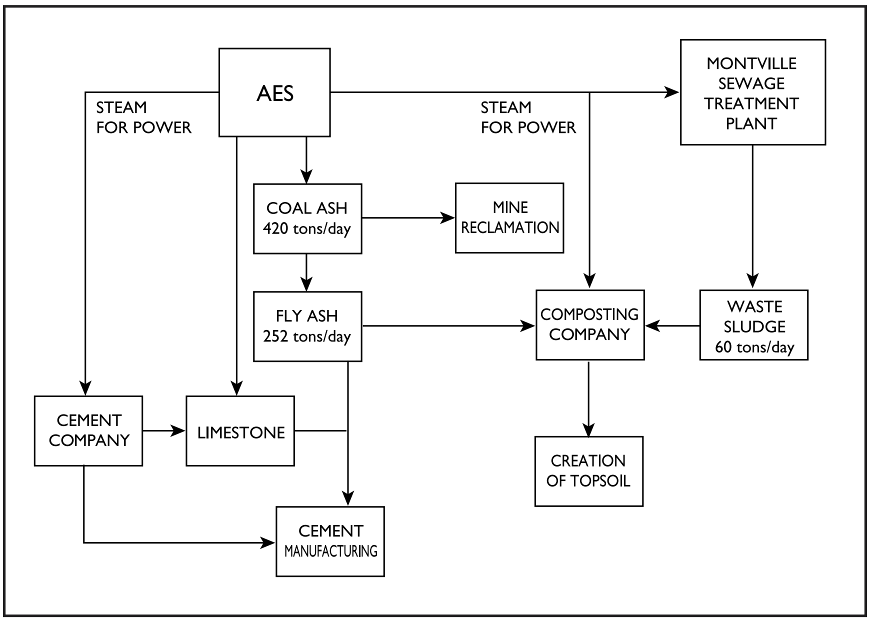

Figure 3 AES Coal Ash Management Possibilities

mately 60% of the total coal ash from a coal power plant. The exact percentage varies, depending on the type of burn mechanisms employed, the type of coal burned, and the efficiency of the plant. From 1990-1996, approximately 20 patents for fly ash products were filed each year, and many others are under investigation (Western Ash Company 1996). Fill uses for fly ash, with no additional processing necessary, include flowable fill, structural fill, road base, asphalt filler, ice control applications, and blasting grit. An example of the commercial use is ReUse Technologies, which markets fly ash under the brand names of EZ Fill (with kiln lime for cementous properties) and Xcel Fill (without kiln lime added) (ReUse Technologies 1996). Other uses for fly ash are cement/ceramic applications, wallboard, gypsum, and other assorted applications. These require some form of processing and additional materials to make the ash into a usable material.

Most of the new technologies are in the construction and agricultural industries. Some examples include a process by Argonne, which developed a chemically bonded ceramic technology which forms a material from ash that is "inexpensive, dense, leach-resistant, and stronger than concrete materials" (Tech Transfer Highlights website 1996). Another option is to use the ash as a fertilizer. ReUse Technologies markets a pellitized ash under the trademark BUCKSHOT®, for use as an agricultural fertilizer (ReUse Technologies 1996). A third example is using ash as a substitute for gypsum. Currently, USG Corporation is opening a new plant to market Sheetrock®, which uses coal ash as its main material source. The plant will be able to make 700 million square feet of wallboard per year. USG plans to have the plant replace one that is making wallboard out of conventionally mined gypsum. Lastly, cement is another potential fly ash product.

The introduction of a cement company to the area is one of the more promising options. Fly ash is already composed of the same materials as cement, but in different ratios.

Another option for combining sludge with coal ash has been developed by Minergy, a company based in Wisconsin. They blend the raw materials and then mineralize them in a high-temperature rotary kiln to produce Durolite. Durolite is a strong, lightweight aggregate which is superior to natural aggregates for structural concrete applications. It is also finding a market in insulating concrete, as fire-resistant material filler, and as a landscape ground cover. The process has the added benefit of yielding recoverable thermal energy, which is used to provide steam and electricity. Minergy is currently using 150,000 tons of ash and sludge annually (Minergy 1996).

The introduction of a cement company to the area is one of the more promising options. Fly ash is already composed of the same materials as cement, but in different ratios. Combining fly ash and lime will produce a material analogous to Portland cement. Most cement production utilizing coal ash has shale, limestone, fly ash, and water as its raw materials. Montville and the surrounding towns have a number of small gravel quarries which could be a source of shale and gravel fill. Additional limestone could be brought in with AES's shipments.

One example of the use of ash in cement production is Roanoke Cement Company, which currently uses about 42,000 tons of coal ash from nine different sources. The equipment and material streams used are similar to those in the cement industry (West Virginia University 1996). One of the benefits of a local cement company would be transportation cost savings. The cement industry is regional in nature, with most of its costs in shipping. The majority of cement produced is shipped less than 300 miles to its end use. By having all of the material sources for the company in the area, monetary and environmental costs would be reduced.

The cement industry is a growing market. Since 1980, production has steadily increased, and in 1995 approximately 86 million metric tons of cement were used in the US, with 13.8 million metric tons imported to meet domestic need (Cement Industry 1996). Connecticut alone had a growth of more than 5% in the cement industry (The Monitor 1997). Utilizing coal ash as a raw material for cement would save the energy involved in mining and processing raw material streams. The American Coal Ash Association estimates that substituting coal ash for cement materials reduces $C0_2$ emissions by 4-5 million tons per year (Cement Industry 1996). The potential impact from less mining and transportation, as well as the good market growth, make this an attractive option for Montville.

Currently, some states are using municipal wastewater sludge as a fertilizer for agricultural soils. By using a mixture of coal ash and sludge, the soils formed are found to have a greater amount of organic material and nutrients available to the plants, are pH balanced, well drained, and are able to retain their minerals with less leachability.

Another promising idea for the use of coal ash is to combine it with another waste stream in the Montville area. The Sewage Treatment plant has a large volume of sludge that currently is incinerated at a cost of $600,000 to $800,000 per year. There are several new technologies that use a combination of coal ash and sludge. One is the production of soil. The potential market for topsoil and other garden fertilizers is huge. In 1994, the US spent over $25 billion on gardening and landscaping.

Currently, some states are using municipal wastewater sludge as a fertilizer for agricultural soils. The problem with this method is that there has been found to be some water runoff contamination and plant uptake problems with the nutrient availability. By using a mixture of coal ash and sludge, the soils formed are found to have a greater amount of organic material and nutrients available to the plants, are pH balanced, well drained, and are able to retain their minerals with less leachability.

Studies by West Virginia University have shown a much higher success rate with apple orchards using the sludge-ash mixture than many of the local, naturally occurring soils. They have also found that the toxic trace elements that can be found in coal ash (such as boron, molybdenum, selenium, and arsenic) are stabilized by the sludge, and that there was much less leaching than in raw coal ash (West Virginia University 1996). One process, ASH-IT, by the University of Alaska, produces a stable, highly fertile soil with no odor in the production process. These soil products are targeted at crops that need a high amount of calcium and sulfur, such as peanuts and soybeans.

Waste Plastics Management

One waste stream that Stone Container and Rand-Whitney share is waste plastic that is removed from recycled cardboard during processing. Each facility produces about 20 tons daily, for a yearly total of 14,240 tons. Currently, this plastic is being landfilled but other options are available. If it were to be incinerated in a conventional waste-for-energy situation, it could potentially produce a vast amount of energy. This is not being done now because the tipping fees at incinerators are about $20 more per ton than the rate at landfill sites.

Another possibility for handling the plastic remains is to convert them into plasma gas using a plasma waste converter (PWC). A PWC is an electrically driven machine that provides an intense field of radiant energy that causes the dissociation of the molecular bonds of solid, liquid, and gaseous compounds or materials of both hazardous and non-hazardous wastes. The molecules of the waste material are separated into their elemental atomic components and then reformed into recoverable, non-hazardous commodity products ready for commercial use. The elemental components of the feedstock can be recovered in different phases:

1. Synthetic gas (Plasma Converted Gas, PCG) that rises to the top of the chamber;
2. Inorganic, glass-like silicates, that collect above the metals in the chamber;
3. Liquid metallic elements, which collect at the base of the chamber.

One waste stream that Stone Container and Rand-Whitney share is waste plastic that is removed from recycled cardboard during processing. If it were to be incinerated in a conventional waste-for-energy situation, it could potentially produce a vast amount of energy.

The PWC requires electricity to operate, but for each unit of electricity used to process waste, approximately four units of energy is recovered in the form of PCG gas. In addition, the PWC reduces the volume of waste by 300 times.

In terms of managing the metal waste resulting from Stone Container's operations, the value of the metals will vary greatly with the composition of the scrap going into the PWC. In general, the metals would be passed through the PWC and the impurities and toxins would be plasmatized and collected as PCG. The metals would be recovered as a conglomerate block, clean of impurities and ready to sell to a metal recycler.

The plastics could easily be converted into PCG gas. PCG gas is made up of carbon, hydrogen, and oxygen, just like fossil fuels. Consequently, it can be used as feedstock to produce more polymers or as a clean fuel for a fuel cell or some type of electricity-producing turbine. According to StarTech Environmental Corporation, 25 tons of plastics would produce approximately 25 tons of PCG (StarTech 1997). The exact amount/ton of waste injected and composition of the PCG produced is dependent on the actual composites of these waste polymers. However, PCG has a current market value of 3.7¢ per thousand cubic feet, and therefore the PWC would turn this polymer waste into a salable, reusable product. In order to determine how much PCG would be produced from SCC's plastics waste, a test must be run on the waste source at a cost of approximately $20,000. Unless toxics are present in the waste stream the PWC will probably be too expensive for SCC for at least the next 5 years.

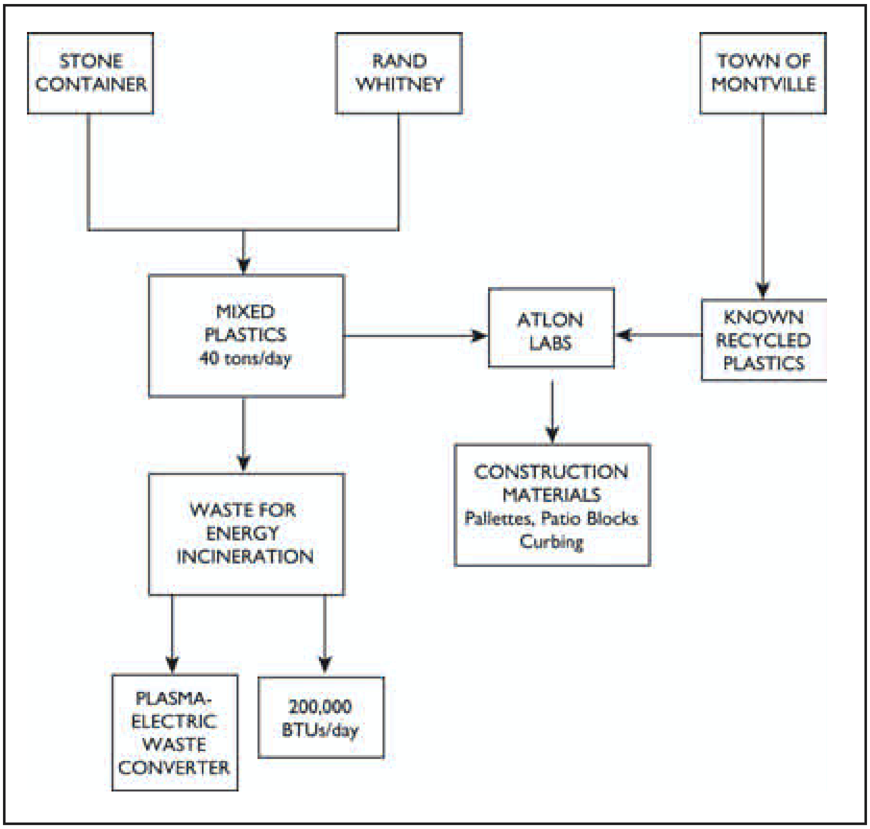

Figure 4 Stone Container Corporation Plastics Management Possibilities

There is another, less capital intensive, more economically viable option for dealing with the plastics wastes. Atlon Labs of Acton, Massachusetts specializes in taking unwanted plastics and developing a product from them. The plastic waste from Stone Container is of a poor quality, being a mixture of many different types of plastics combined with contaminants of wood pulp and water. Atlon has experimented with samples of the plastic from Stone Container and found that by mixing it with a plastic waste stream of a known consistency, they are able to form a feedstock that is usable. Atlon uses a process that takes the feedstock at room temperature, heats it to molten temperatures, and then uses an injection molding process to make its products. Most of what would be made are high volume products such as pallets, curbing, and patio blocks. Atlon Labs operates independently and has a viable market niche.

There is another, less capital intensive, more economically viable option for dealing with the plastics wastes. Atlon Labs of Acton, Massachusetts specializes in taking unwanted plastics and developing a product from them.

Atlon has extensive experience in the waste disposal business. It operates "nodes" of business around the country where there are waste streams that can be used. They capitalize on a cheap abundant raw material (most businesses either give the Atlon facilities the plastics for free or even pay them to take it at a cheaper cost than it would cost them to dispose of it, and use a process that allows them to recover contaminated materials). Currently Atlon is very interested in using the plastic from SCC and Rand-Whitney, but it needs to expand its capacity to be able to deal with the volume coming to its facilities. It also needs to find a consistent source of waste plastic with a known consistency, such as milk jugs or soda bottles. One possible such source might be from Montville and local communities. Currently the Groton Recycling Center, which sorts the recyclables for Montville and 10 other local communities, has a curbside recycling program that produces approximately 400 tons of #2 plastics and 100 tons of #1 plastics each year. The Mohegan Sun uses an independent contractor, but also could be a potential source of recyclable plastic. While these sources clearly will not provide all of the plastic necessary, it would be one way of helping to close the loop in this area.

Introduction of Fuel Cells

Since both Northeast Utilities and AES-Thames are energy producers, it is crucial that they stay abreast of changes in the electricity industry. At the forefront of this industry is the fuel cell, an alternative form of electricity production. A fuel cell operates similarly to a battery in that it supplies electricity by combining hydrogen and oxygen electrochemically, without combustion. In this process, the hydrogen is usually produced through a steam-reforming fossil fuel process and the oxygen is usually derived from the air. However, unlike a battery, the fuel cell does not need to be recharged, only refueled.

The cell consists of two electrodes (an anode and a cathode) sandwiched around a particular type of electrolyte. As oxygen passes over one electrode, hydrogen passes over the other to produce electricity, water, and heat. Natural gas is the most commonly used fuel. Fuel cells are classified by the type of electrolyte that they use. Common types include: alkaline (AFC), phosphoric acid (PAFC), Proton Exchange Membrane (PEM), Molten carbonate (MCFC), and Solid Oxide (SOFC).

Fuel cells can be used for a variety of purposes: they can be used as a prime power supply, as an interruptible power supply, or as a cogeneration system. One of the advantages of fuel cells is that they can be sized to accommodate a variety of capacity needs. The best potential application seems to involve cogeneration where the fuel cell is used to offset conventional energy consumption by reclaiming waste heat, as in the preheating of boiler feedwater.

Fuel cells can be used for a variety of purposes: they can be used as a prime power supply, as an interruptible power supply, or as a cogeneration system. The best potential application seems to involve cogeneration where the fuel cell is used to offset conventional energy consumption by reclaiming waste heat, as in the pre-heating of boiler feedwater.

Perhaps the greatest benefit of fuel cells, however, is their low environmental impact. Since an electrochemical process, rather than a combustion process, is used to produce electricity, emissions are generally much cleaner and more benign. The main "waste" products are potable water and CO_2. Natural gas utilization and efficiency can be greatly improved, especially when coupled with cogeneration and heat recovery, lowering the amount of energy needed to produce electricity.

As new technologies find alternative fuels to natural gas, consumption of fossil fuels can be reduced. One particularly interesting alternative that is being researched is the use of methane gas piped from landfills as the source of fuel for the cell. The methane produced by a local composting company and by the

Montville Landfill, located only a few miles away, could be used as a source of fuel (see Figure 5). This would enable AES or Northeast Utilities to tap into a reservoir that is not currently being exploited, lessening reliance on fossil fuels extracted from virgin territories. Also, the potable water produced by the fuel cell could be piped into the existing water line infrastructure. This new source of water could help to alleviate water shortage problems.

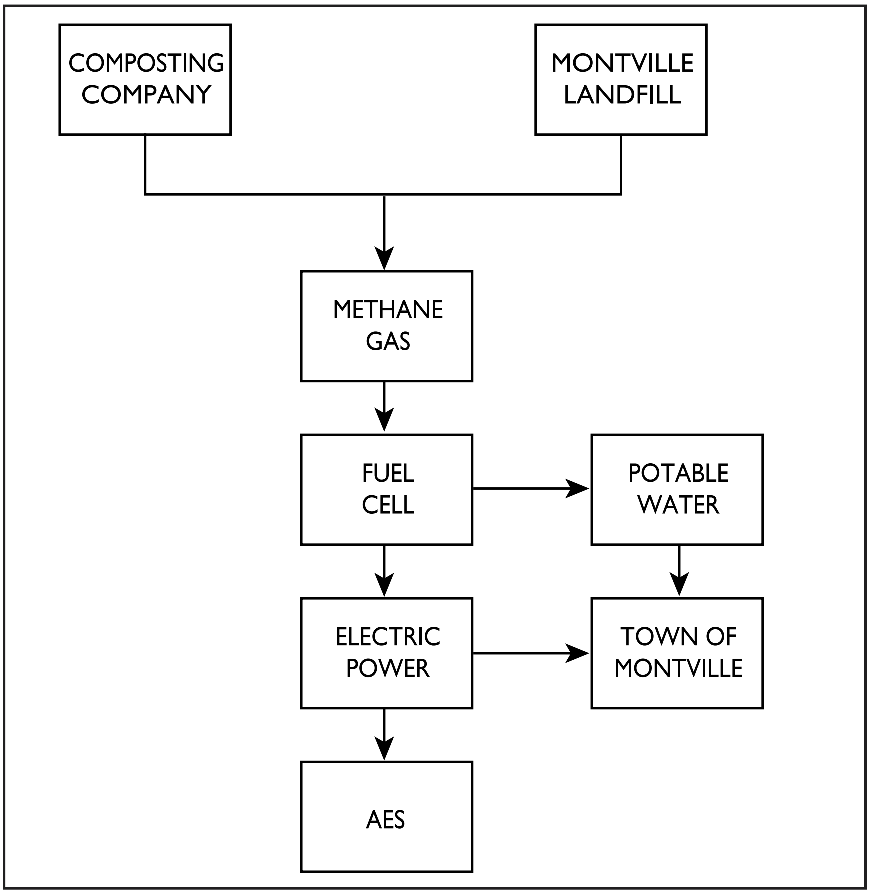

Figure 5 Fuel Cell Applications

Scenario 3: Brewery

Craft Brewing

The opportunities for increased efficiency in material and energy flows discussed in Scenario 1 and Scenario 2 have laid the foundation for Scenario 3. Scenario 3 offers a more intensive illustration of how we can develop an EIP in Montville (see Figure 6). The soil that the proposed EIP has the potential to produce, the open land in the area, and the excess energy in the form of steam create perfect conditions for the establishment of a brewery. Just how a brewery might be established and sustained in Montville will be examined below.

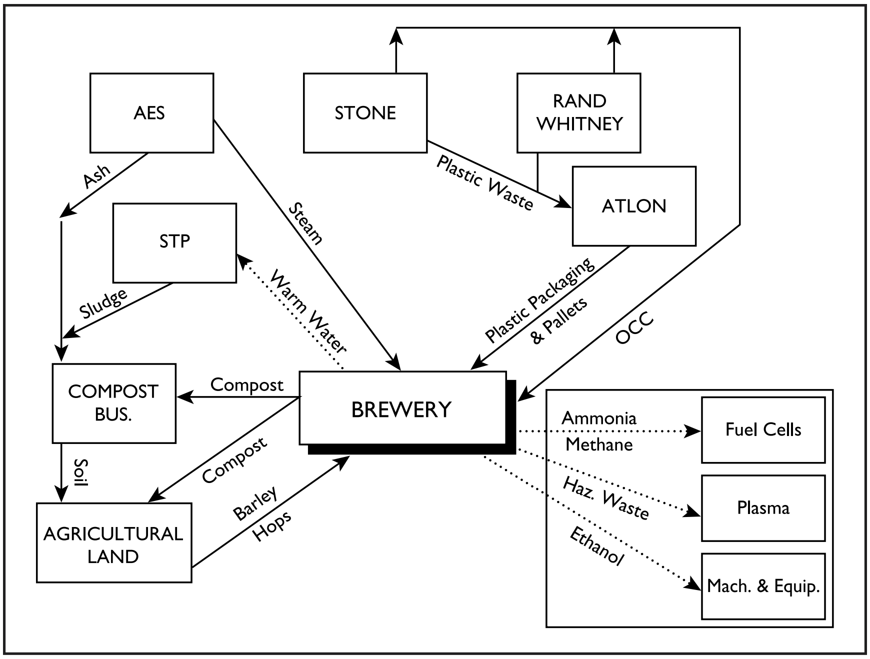

Figure 6 Montville Brewery Vision

A craft brewer, who is designated for production below 15,000 barrels a year, would be ideal for the Montville area. Craft brewers represent only 1.5% of the U.S. beer market, but have enjoyed a 30-40% growth in production per year over the last five years (Samuel Adams 1996). These small volume, high quality beers have enjoyed tremendous popularity, lending confidence to the viability of establishing such an enterprise. Furthermore, the characteristic niche marketing of such businesses could allow a Montville brewery to promote the environmental sensitivity of the beer and maintain a small distribution area.

Malt, hops, water, and yeast are the necessary ingredients to make beer. We will avoid what are called "adjuncts." These are starches and other preservatives such as potassium metabisulfite, sodium metabisulfite, and ascorbic acid that make beer lighter and give it a longer shelf life. Not using adjuncts keeps the material flows simple and meets the German Reinheitsgebot of 1516, the highest purity standard in the brewing industry.

The plan for the craft brewery relies on 5 acres of local hop production and 157 acres of local barley production. These will produce enough raw materials with existing resources to produce 15,000 barrels a year. Additionally, the yeast will be cultured in the facility on a growing medium. It is our belief that area soil conditions ameliorated by EIP produced soil and brewery compost from the brewing process will provide an excellent nutrient base for the crops. Furthermore, we feel the growing season is adequate, as the location is further south than the most famous hop regions in the world.

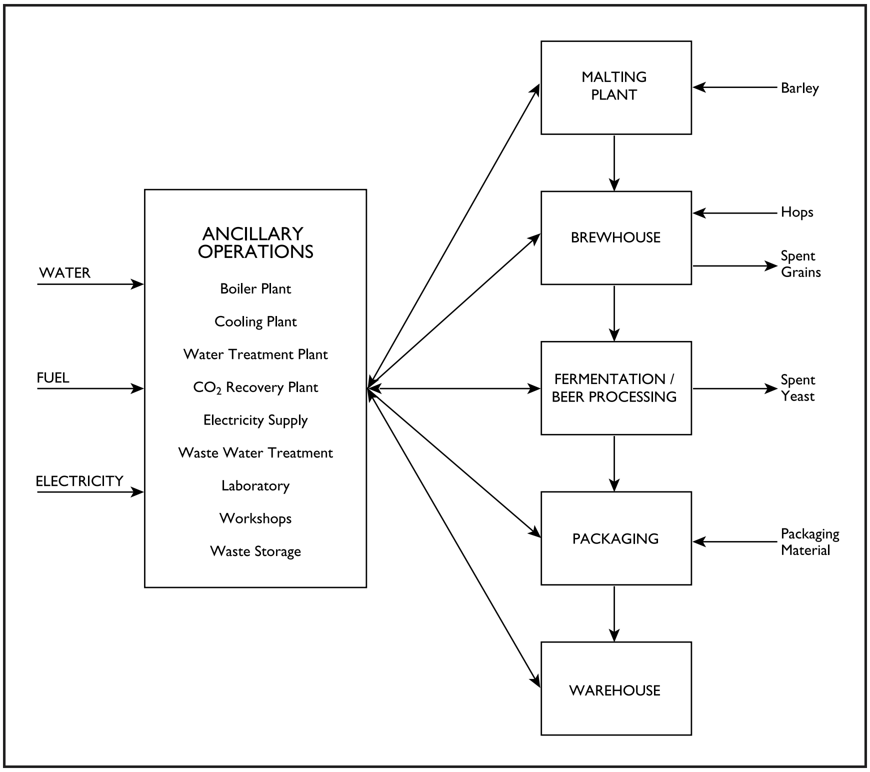

Figure 7 Brewery Operations (United Nations 1996)

Beer Production

The fundamental processes of beer production are malting, brewing, fermenting, and packaging (see Figure 7). In the malting process, barley is soaked in water and then the partially sprouted grain is kiln-dried and roasted, forming malt (Samuel Adams 1996). The malt is then combined with water, heated, and strained. The resulting substance (commonly called the "wort") is then boiled with hops and strained again. These two steps, which have been greatly simplified here, comprise what is actually considered the brewing process. The fermentation process follows, which consists of the addition of yeast to metabolize the sugars in the mixture, forming alcohol and CO_2. The yeast is recovered after its use and can be re-used up to ten times (United Nations 1996). At this stage the beer is ready for any number of packaging alternatives.

Environmental Concerns

Figure 8 illustrates a simplified resource flow of a brewing facility. The material usage obviously varies by specific product types and production technologies and techniques. The small quantities of residuals generated by our brewery make it difficult to conceptualize tremendous environmental impact. However, there are some environmental impacts associated with brewing. Some of these include: surface water pollution or depletion, ground water pollution or depletion, global warming (CO_2 emissions), acid rain and other air pollutants (NOx and SO_2), and waste disposal.

Our EIP scenario addresses each of these categories. To begin, air pollution concerns (which typically are associated with gas or oil boilers) could be alleviated through the use of steam as power for the majority of the operation. With our target of 15,000 barrels, the steam requirements could easily be met by AES. It is perhaps helpful to keep in mind that the plan is for a brewery without a sophisticated heat recovery system. Heat-consuming processes like boiling, sterilization, and bottle washing could be minimized by good insulation, maintenance, and/or a steam condensate return system (United Nations 1996). A steam condensate return system would make heat available for other heating processes such as cleaning and pre-heating of fluids before the boiling process.

Additional energy requirements could be met by the recovery of ammonia from the composting of spent grains. The composting operation could also be skipped altogether with the conversion of spent grains into methane. This type of technology is already in place at the brewing giant Beijing Brewery which produces its steam needs through methane-powered boilers (Gertler and Ehrenfeld 1996). There is also the potential for some alcohol-bearing waste streams to be distilled into ethanol, which obviously has fuel potential. While these gas conversion techniques may have resulting air pollution impacts, the potential for resource use savings is enormous.

It is difficult to discern if water consumption would be an issue. With the abundance of ground water and the capacity of the Montville Sewage Treatment Plant to perform secondary treatment, it seems likely that the supply would be adequate if augmented by on-site treatment to raise water to brewing standards. Pollution issues could be addressed by the combined treatment of brewery and municipal wastewater that can be beneficial for both parties on economic and environmental fronts. One reason for this is the biodegradable

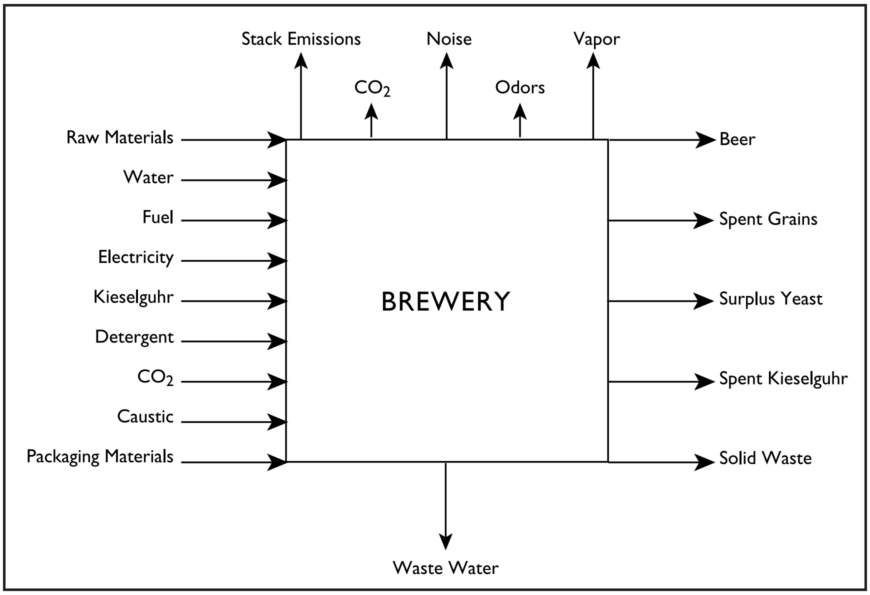

Figure 8 Simplified Resource Flow of Brewing Operations (United Nations 1996)

organic compounds in brewery wastewater that are conducive to the removal of nitrogen through common de-nitrification processes.

Another synergistic benefit of the combined water treatment is the biological treatment processes that are enhanced by the warm brewery water (United Nations 1996). This is particularly important in colder areas such as Connecticut. Wastewater problems may also be alleviated through land application. Where proper soil and climatic conditions exist, land application could be an extremely attractive solution. The crops grown with such substances are typically subject to regulatory requirements.

Ground water pollution from breweries is typically associated with the storage of fuels and cleaners in underground tanks. Where tanks are necessary, above ground tanks will be used. Obviously, the demand for fuel tanks will be minimal, due to our energy recovery strategies. Where cleaner use is necessary, we will use Iodophor™ an iodine based cleaner engineered to avoid the problems associated with chlorine (Havnold and Nickerson 1993).

Pollution issues could be addressed by the combined treatment of brewery and municipal wastewater that can be beneficial for both parties on economic and environmental fronts. One reason for this is the biodegradable organic compounds in brewery wastewater that are conducive to the removal of nitrogen through common de-nitrification processes.

A very interesting concept particularly useful to breweries is to address the wastewater and waste disposal issues at the same time through the use of wastewater materials recovery and the subsequent composting of suitable materials. As demonstrated by the Anheuser-Busch brewery in Baldwinsville, New York, composting reduces the amount of brewery waste that must be landfilled by 80 to 90 % (Beers and Getz 1992). This facility, which produces 7 million barrels annually, generates 30,000 dry pounds of bio-solids a day, equivalent to about 120,000 pounds of wet sludge. The composting process is quite simple and has yielded some astonishing results. From 1989-1991 an annual average of 24,633 cubic yards of sludge was composted, yielding an average of 28,766 cubic yards of compost. This has resulted in some $ 1.1 million per year in tipping-fee savings.

Obviously, the craft brewery would operate on a different scale, generating only about 13.42 cubic yards of compost annually. But this is only the beginning of the potential efficiencies of the EIP. Inexpensive plastic beverage containers and shipping pallets are a very realistic possibility considering the area's plastic surplus and the resulting product possibilities from Atlon Labs. An array of cardboard containers could also be produced easily by Stone Container and Rand-Whitney. To reduce needed landfill space and resource use, returnable bottles are also common to brewery plans. This idea, however, brings up some interesting environmental trade-offs. Bottle-washing operations use large amounts of energy, water, and cleaners. The use of non-renewable containers obviously lessens these environmental burdens while increasing others. One redeeming quality of washing operations is that some of the commonly recovered materials such as paper pulp, cigarette butts, aluminum, and plastics have the potential to be recycled or used in our many waste recovery scenarios.

Policy and Regulatory Concerns

There are many aspects of local and federal policy that must be considered in coordinating an EIP in the Montville area. To begin, the Montville Environmental and Economic Coalition should be involved in the development of the park from the outset. This group, which formed due to the recent growth in the area spurred by the Mohegan Sun Casino, is the embodiment of local environmental concerns. The extent of its power is not clear. However, operating without communication with the Montville Environmental and Economic Coalition is not advisable.

On the federal level, the Resource Conservation and Recovery Act (RCRA) also poses some interesting questions about the possibility of an EIP becoming operational. The confusing language of RCRA does not make clear what materials can be reused, recycled, or reclaimed. It is generally believed that RCRA does not allow for much innovation in this area. Another difficult aspect of RCRA is the regulation of hazardous materials. Several hazardous and potentially hazardous materials that are mentioned as material flows in this report have the potential to create enormous permitting and paperwork requirements. When planning for the use of hazardous materials in the EIP it will be advisable to work closely with counsel and regulators to determine precisely what is permissible under the law. It is encouraging to note that some regulatory burdens have been lifted for industrial ecology scenarios that are beneficial and pose no significant threat to the environment (Beers and Getz 1992).

The last regulatory concern is single-medium permitting. Clearly there are many economic and environmental reasons why an EIP would want to be regulated as one entity. However, there are liability concerns for companies associated in this way. Several legal questions remain unanswered regarding the liability of companies that are regulated as a single unit when one or more companies engage in an illegal activity.

The government has and will have a tremendous role in the future of eco-industrial parks. The regulatory structure as it stands now is the largest obstacle for the development of such initiatives. More flexibility will have to be integrated into the law-making process not only in the U.S. but around the world. To find the systemic solutions that are consistent with solving environmental problems, new directions in policy will have to be charted. It is with this in mind that the researchers of the Montville EIP call for communication among all EIP stakeholders and a commitment to EIP research domestically and internationally in order to ensure the vitality of this innovative concept.

Anheuser-Busch Composting

The Anheuser-Busch brewery in Baldwinsville, New York has turned to composting as an innovative way to deal with the large amounts of solid waste typical of brewing operations. With land application limited because of the harsh winter weather, incineration less desirable because of air pollution concerns, and the high cost of land-filling, the brewery composts its residual sludge in an attempt to avoid economic costs and recover some of the nutrient and mineral value of the solids. The composting operation mixes de-watered sludge cake, sawdust, and recycled compost in 12 bays measuring 5.5' x 6.6' x 216'. A hydraulic blender mixes the compost in each bay and discharges 12 feet of finished compost daily.

The environmentally and economically sound composting process was developed by International Process Systems of Lebanon, Connecticut. The process uses daily mixing, and exacting aeration and temperature controls, to achieve the extraordinary results. A bio-filter of compost, sawdust, and coarse sand is used to absorb the composting gaseous by-products to avoid odor problems for the nearby residential community. Temperature control is achieved by automatic thermocouples attached to the side walls of the bays. The programmable sensors maintain the 55-60°C temperature by the cycling of aeration fans.

In a collaborative partnership with NYNEX, the brewery has also been experimenting with using old telephone books as a replacement for the sawdust. Additionally, the recent addition of an anaerobic pretreatment facility that is supposed to reduce brewery waste solids by 33% has led to exploration of use of the excess composting capacity. Beechwood chips and packaging materials are some of the experimental materials. Success with these materials would make the composting even more attractive in terms of EIP possibilities.

REFERENCES

AES Corporation, AES Annual Report. 1996.

Beers, A. and T. J. Getz. 1992. Composting biosolids saves $3.3 million in landfill costs. *Biocycle*. 33, 5: 42.

Boulder Community Network/ Environmental Center/ Boulder Earth First/ Salva Tu Sierra. 1997. http://ben.boulder.co.us:80/environment/earthfirst/LaSierra/Stonecol.htm.

Bryne, H.S. 1996. Power pays. *Barron's*. January 26, 1996.

Cement Industry. 1996. http://www.portcement.org/indecon.html

Coal Ash Resources Research Consortium. 1995. http://www.eerc.und.kodak. edu/9395bien/p285.html.

Cropper, C. 1993. A four letter dirty word. *Forbes*. January 17: 58.

Dow Chemical Co. 1995. Allyns Point Pamphlet. Gales Ferry, CT.

Dow Chemical Co. 1996. *Continuing the Responsible Care Journey*. Progress on Environment, Health and Safety.

GeoNews. 1996. Coal Ash - An Environmental Bonus. http://www.inns.uiuc.edu/lsgsroot/news/geonews/may96/coalash.html

Gertler, N. and J. Ehrenfeld. 1996. A down-to-earth approach to clean production. *Technology Review*, February/March.

Havnold, A. and G. B. Nickerson, 1993. Factors affecting hop production, hop quality and brewer preference. *Brewing Techniques*. 1: 1.

Minergy (Wisconsin Energy Corporation). 1996. http://www.ceramics.com/ minergy/process.html#INTRO.

The Monitor. 1997. A Monthly Analysis of Trends in the Construction & Cement Industries. 6, 12:1-13.

ReUse Technologies. 1996. http://www.reusetech.com/abstract.html.

Salpukas, A. 1997. Utility deal aims to cut cost of power. *New York Times*. February 6, 1997.

Samuel Adams. 1996. http://www.samadams.com/beereduc/ingred.htm.

Startech Environmental Corporation. 1997. http://www.startech.net

Stone Container Corporation. 1996. Annual Report.

Stone Container Corporation. 1997. *The environmental challenge*. Corporate environmental report.

Tamborra, Jack. 1997. Government Affairs Manager for Northeast Region, Dow Chemical Co. personal communication.

Tech Transfer Highlights. 1996. http://www.am.gov/HD/ash.html.

United Nations, 1996. *Environmental management in the brewing industry*. United Nations Environment Programme, v. 106.

Western Ash Company. 1996. http://www.primenet.com/~wash.

West Virginia University. 1996. Coal Ash for Reclamation. http://www.wvu. edu/~research/techbriefs/coalashtechbrief.html.

FURTHER READING

Cohen-Rosenthal, E., T. McGalliard and M. Bell. 1996. *Designing eco-industrial parks: the North American experience*. Cornell Center for the Environment.

Franklin, R. 1996. Startech Environmental Corporation. *The Wall Street Corporate Reporter*. September 16:36-39.

Wallingford, Connecticut Eco-Industrial Park: A Question of Scale 1999

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ABSTRACT

This paper assesses the potential for the development of an eco-industrial park (EIP) along an industrial corridor in a small New England city. We propose present and future linkages among existing businesses and recommend new industries that might be attracted to the Wallingford, Connecticut area to share the inputs and outputs of EIP members. We outline short, middle, and long term strategies for achieving environmental and financial benefits through the application of industrial symbiosis principles.

Five firms from an original list of seven agreed to participate in this project. Representatives from Ametek, Connecticut Steel, Cytec Industries, Resource Recovery, and Ulbrich Specialty Steel Mill were interviewed by our team, and we were afforded a site visit to each operation. Additionally, telephone interviews were conducted with representatives from the Town of Wallingford, local power and water utilities, and Suzio Concrete.

INTRODUCTION

Industrial ecology views industrial systems as part of natural systems and attempts to apply lessons about natural systems to the operation of industrial facilities. The eco-industrial park model offers a primary means to apply these tenets. Through EIPs, industrial ecologists attempt to break down the "once-through" paradigm that characterizes most production processes. EIPs form around a locus of businesses that need not be co-located. They may share energy, water, residues, information, management systems, marketing, or other functions as a basis for achieving greater performance than individually possible.

Wallingford has two key ingredients that make it an ideal candidate for the successful creation of an Eco-Industrial Park: businesses with overlapping inputs and outputs, and attractive business amenities that can induce the siting of additional EIP partner industries. Perhaps as important, however, is the willingness of the existing businesses and Wallingford's Economic Development Coordinator to work with each another to achieve the potential efficiencies of an EIP arrangement. Despite the favorable climate for new industries, the economies of scale needed by the businesses proposed could be limiting factors in their establishment. Reducing this scale or drawing markets from a larger area will be instrumental in determining the ultimate feasibility of these new ventures.

Finally, the promotion of a virtual EIP and the integration of existing industries into an ecological and aesthetic plan can serve as the central theme for future development in Wallingford. Such a unified vision could rightly be termed a sustainable development plan for Wallingford that would further integrate firms into the natural environment and the community. This vision could establish Wallingford as a national model for sustainable development, differentiate it from other northeastern neighbors, and offer the town a significant competitive advantage over other communities in the future.

Most participants do not join EIPs solely for environmental ends; EIPs and industrial ecology are premised upon the belief that opportunities exist to improve profitability through a systems approach that spurs superior environmental management. In fact, the goals of EIPs are twofold: "to improve economic performance of the participating companies while minimizing their environmental impact" (Lowe and Warren 1996).

The goal is to facilitate materials exchange among existing businesses to reduce costs, increase profitability, and improve environmental performance. At the same time, an EIP project offers an opportunity to spur further economic development, as the remaining residues and demands for further inputs to the manufacturers will suggest other viable businesses that could join the park in order to facilitate closed loop material flows within the EIP

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As part of our investigation, our team reviewed the Plan of Development created by the Town of Wallingford's Planning and Zoning Commission (POD Update 1993). In this document the Commission stated that its main objective was to "create an atmosphere that is hospitable to encouraging commercial/ industrial development in Wallingford." Specifically, the Commission identified several goals including:

- to develop a town-wide comprehensive infrastructure plan (water, sewer, electric, traffic, etc.);
- to encourage the efficient design/ development of buildings and property;
- to encourage further examination of the commercial areas along Route 5 from South Main to Cedar Lane to permit expansion of Route 5 businesses while protecting the integrity of the abutting residential neighborhoods;
- to provide appropriate areas for future commercial and industrial development;
- to expand the use of recycled materials for re-paving of roadways;
- to support the efforts of the utility department in water and energy conservation;
- to support additional water sources to meet future growth.

These focus areas were evaluated in the context of this industrial ecology project and have been incorporated where possible. Considering the time frame (1993) in which the Planning and Zoning Commission developed these goals, our team believes they are visionary and are consistent with industrial ecology principles. The Commission's stated goals help to make Wallingford an ideal location for the promotion of EIPs. With further emphasis, industrial ecology and EIPS could serve as the theme for new development in the town. Wallingford could work with the community and businesses to promote itself as a center of sustainable living, integrating its industry into the natural environment and the progressive community.

SUMMARY OF RECOMMENDATIONS

The major themes of our team's recommendations fall into three categories: 1) materials reuse, 2) water reuse, and 3) establishment of an "industrial campground."

Materials Reuse

Several waste streams were found to be logical inputs to existing industrial operations. Where no matches were identified and ample quantities of residues were available, new businesses were proposed. The more significant streams include liquid waste for energy recovery, ash for concrete, scrap metal for processing in a mini-mill, and biological treatment sludge used as fertilizer.

Water Reuse

Cytec Industries has a surplus of water that can be used to meet the needs of companies in the area that currently use town water. Our team believes that water requirements of a proposed power station can be met by using the effluent of the town sewage treatment plant in conjunction with a water-use trading program for diversionary users of water from the nearby Quinnipiac River.

Industrial Campground

A network of services should be created within the industrial park so that future tenants can set up operations quickly and be responsive when markets evolve. In addition to the typical electrical, potable, and sanitary services, the industrial campground would provide steam, gray water, natural gas, and specialty gases (i.e., argon, hydrogen, and nitrogen).

The time horizons for proposed changes are short-term (one to two years), intermediate-term (three to five years), and long-term (six to ten years). The following is a summary of our team's recommendations according to the implementation schedule:

Short-term

- Exchange high BTU value residues;
- Lay pipes for joint water, natural gas, and industrial gas usage;
- Share transportation of scrap metal;
- Use sanitary sludge as a lawn fertilizer;
- Develop a formal Council on Industry and the Environment.

Intermediate-term

- Site four new businesses in the Wallingford area:
  - ash processor
  - wallboard manufacturer
  - industrial gas manufacturer
  - steel mini-mill
- Use the Council on Industry and the Environment as a vehicle to examine linkages among industries and develop an EIP plan for the area;
- Use wastewater from the Wallingford Publicly Owned Treatment Works (POTW) as cooling water in the planned combined cycle power plant;Develop a water credit trading scheme to mitigate diversions from the Quinnipiac River.

Long-term

- Create a household hazardous waste recovery and recycling program;
- Mine the municipal solid waste landfill for metals;
- Research and implement programs to reduce the volumes of ash, industrial gases, and sludge in process;
- Convert the waste-to-energy plant to a cogeneration plant, selling both steam and electricity;
- Develop an aesthetics code, voluntary environmental initiatives, and shared service functions through the Council on Industry and the Environment;
- Build a canal to carry cooling water through the park;
- Extend planned trails through the area;
- Construct wetlands to treat wastewater.

TOWN OF WALLINGFORD

Situated in Connecticut roughly midway between Hartford and New Haven, Wallingford was founded in 1670 by English Puritans who moved North from New Haven. The industrial revolution eventually changed the character of Wallingford from an agricultural community to a large producer of silver and silverware. Today, Wallingford has grown to a town with over 41,000 people and 1,400 businesses (Malone and MacBroom 1996, Wallingford Economic Development Commission). The ultimate population potential for Wallingford is 52,798 (based upon the zoning map as of 1993 and an occupancy density of 2.6 persons per dwelling) (POD Update 1993). The total acreage of Wallingford is 24,920 acres. The three primary types of land use are residential, commercial and industrial.

The industrial growth in town increased significantly after World War II. The founding companies were Wallace Silversmith, Allegheny Ludlum, Judd Drapery, Ulbrich Steel, Eyelet Specialty, American Cyanimid and Parker Mills. Of these, only Allegheny Ludlum, Ulbrich and Cytec Industries (formerly

Cyanimid) are still in operation. Three additional industrial areas within Wallingford have been developed in the last 35 years.

Wallingford has managed to maintain its industrial base, while many surrounding areas, notably New Haven and Bridgeport, have lost their keystone industries. Significant inducements to businesses have helped the town maintain its industrial keystones while other Connecticut cities have suffered. Wallingford benefits from a central location with excellent access to transportation arteries. Its primary industrial corridor boasts easy on/off from I-91 and Route 15, and sits midway between the east-west arteries of I-95 and I-84. Wallingford also offers access to both passenger and freight rail lines, operated by Amtrak and Conrail respectively (Wallingford Economic Development Commission). These transportation options provide Wallingford businesses easy access to all the major markets in the central and eastern United States. The 500-mile radius surrounding Wallingford includes all cities between Boston, Cleveland, and Washington. Two-thirds of all Canadian consumers residing between Toronto, Ottawa, Montreal, and Quebec also live within the 500-mile reach of Wallingford.

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The zoning as of 1993 (latest available data) designated 3,935 acres for industrial use. Of this amount approximately 25% is estimated to be vacant. Of the parcels that are developed, fewer than 20% are covered with buildings. These figures indicate that there is ample space available for additional industrial growth. An additional 150 acres are slated for industrial development by 2010 (Milone and MacBreen 1996).

Wallingford has three municipally owned and operated utilities – electric, water, and sewer. The electric operation was created in 1899 as Borough Electric. Today, as it owns and services all of the distribution system in Wallingford and North Branford, the Town has negotiated directly for wholesale electricity rates on behalf of the entire community. As a result, area businesses pay some of the least expensive rates for power in New England (Wallingford Economic Development Commission). Wallingford is one of six municipalities that have been exempted from participating in the deregulation of power.

The electrical utility also owns a small power generating plant, the Alfred Pierce Station, which operates infrequently for peaking purposes by burning oil. There are plans to construct a 540-megawatt combined cycle power station. This plant will be owned and operated by Pennsylvania Power and Light Company and may be sited on the Pierce property.

The water utility maintains four reservoirs and three wells to supply water to customers. Three of the reservoirs are channeled to Pistapaug Pond, where water is drawn out and treated. A new water treatment plant, with a maximum capacity of 12 million gallons per day (MGD), was built in the early 1990s. The average quantity of water treated is 5 MGD, of which 37%, or 1.85 MGD, is provided to industrial users. The industrial potable water use is projected to increase to 2.12 MGD by 2010 (Malone and MacBroom 1996).

The sewer utility completed an eight-MGD treatment facility in 1989. This is an advanced secondary treatment plant that uses rotating biological disks followed by secondary settling, post aeration and ultraviolet disinfection (POD Update 1993). The average flows are currently 6 MGD (E. Kruger, personal communication).

EXISTING FACILITIES

Initially, seven Wallingford businesses were approached to participate in the project. While two declined, citing proprietary concerns and time constraints, five participated. Two other facilities, Suzio Concrete and the Pennsylvania Power and Light Company electric plant (proposed for development by the Town of Wallingford), were contacted as potential future partners. All five of the initial firms are located in close proximity to each other and enthusiastically embraced the opportunity to share materials.

Company Overviews

Ametek Specialty Metals

Ameteck Specialty Metals produces unusual drawn wire, rolled strip metal, and shaped components from specialty metal powders that are manipulated under high-temperature conditions (see Appendix B for complete materials inventory). Nearly all off-specification metal or scrap is recycled locally or returned to Ametek's parent company for reprocessing. The facility receives frequent shipments of hydrogen and liquid nitrogen, which it injects into the production processes to maintain a stable, non-oxidizing atmosphere. Minimal amounts of water are drawn from the city on a daily basis as make-up water and only

Figure 1 Ametek Speciality Metals

minute quantities are discharged to a Publicly Owned Treatment Work (POTW) via truck. Ametek would like to expand, but is spatially constrained by wetlands. The plant also seeks users for off-specification, high-carbon, pure iron powder, and iron aluminide powdered alloy.

Connecticut Steel

Connecticut Steel rolls plain carbon steel billets into wire coils and rebar for concrete reinforcement. The facility employs large quantities of electricity and natural gas, and obtains irregular, though sometimes large, quantities of water from the city. Connecticut Steel's primary residues are a wet, iron oxide, known as mill scale, and scrap steel. The company pays for the removal of the mill scale and sells its steel to a Waterbury dealer (see Appendix B for details of all residues).

Figure 2 Connecticut Steel

Cytec Industries Incorporated

Cytec Industries is itself an industrial park of sorts, comprised of three businesses: Cytec Industries (resins), A.C. Molding (thermoset molding compounds), and Cyro Industries (thermoplastic molding compounds). Many of the processes combine organic chemicals to produce molding compounds or resins. In addition to these chemicals (detailed in Appendix C), the park employs steam and large quantities of energy. Because a high humidity environment ruins one of its products, Cytec must dehumidify its largest building. As an indirect result, the facility employs large quantities of non-contact, non-toxic cooling water on a daily basis. The majority of this water is drawn from deep wells and most is eventually discharged into the Quinnipiac River, which abuts the company's property. In addition to non-contact cooling water, Cytec also uses a substantial quantity of water within its manufacturing processes. An onsite industrial wastewater treatment plant is maintained to process the water biologically, resulting in large volumes of sludge. Cytec has roughly 100 acres of undeveloped land available on its property and would consider proposals for further development of the land.

Figure 3 Cytec Industries Incorporated

Resource Recovery Facility

Resource Recovery Facility is an 11-megawatt power plant fueled by municipal solid waste, or trash. In addition to operation and maintenance-related wastes, the mass burn waste-to-energy facility also produces 42,000 tons of mixed ash annually (see Appendix D). Nearly 230,000 gallons of water are used daily, drawn from city water to make up for evaporated cooling water.

Figure 4 Resource Recovery Facility

Ulbrich Stainless Steel

Ulbrich Stainless Steel re-rolls steel and titanium under high temperatures to create rolls of particular thickness and quality. Like Ametek, Ulbrich consumes large quantities of industrial gases, including argon (See Appendix E). Since the firm's metal wastes are recycled largely by local handlers, chemical residues with high-BTU value and sand contaminated with oil comprise the bulk of the firm's wastes. Ulbrich requires only small quantities of make-up water.

Figure 5 Ulbrich Stainless Steel

Previous Interaction Among Clients

Wallingford area businesses do not have a strong history of interaction with one another. Project clients cited only three examples of loose interactions that have previously occurred. Cytec Industries once received its steam from the adjacent Resource Recovery Facility. While the pipe between the facilities remains intact along the Route 5 right-of-way, Resource Recovery discontinued service a few years ago, as it became more economic to optimize output for the sale of electricity. There are currently no plans to renew this relationship, and Cytec currently fulfills all of its steam needs with its own natural gas-fired boilers. Some of the area businesses have conceived a plan to jointly fund a natural gas spur pipeline to deliver fuel at prices below those offered presently by utilizing the Yankee Gas pipeline. The businesses hope that any EIP project might help them to facilitate the relationship necessary to support this gas project. Finally, some personnel among area businesses belong to and attend meetings of the same engineering society, and some are members of the local emergency planning committee (LEPC).

TARGET ISSUES

In the next section, different scenarios for the Wallingford EIP will be discussed, beginning with a short-term (one to three year) scenario, moving through a three-to five-year scenario, and finishing with a long-term plan (five to ten years and beyond). The major themes of these scenarios are highlighted below and address metals flows, water supply, ash reuse, and the creation of an industrial campground.

Materials Reuse: Metals and Ash

There are two remarkably large residue streams emitted from our facilities of interest. The largest is scrap metal. Three of the five industries that were studied manufacture steel products. Scrap from cutting and trimming the raw material while being processed results in an annual production of 18 million pounds of scrap metal. Currently, individual facilities are trucking the scrap metal off site for eventual recycling.

The largest output stream of the Resource Recovery Facility is ash. The ash is a mixture of two residue streams: bottom ash, left in the incinerator as the trash burns, and fly ash, produced from air filtration devices as hot gases leave the plant. Currently the plant is paying for the removal and eventual landfilling of the 42,000 tons produced yearly.

As research over the past two decades has shown, there are many viable uses for ash as a product. Because it exhibits the same engineering properties as sands, gravel, and clays, bottom ash performs well as an aggregate in cement, concrete, and asphalt (ASH 1989). It has also been used as a landfill cap, as a sandblasting material, to reclaim land, and to build sound or wind barriers (ASH 1993, ASH 1996). Fly ash has different properties; most significant is the hefty quantity of calcium sulfate, a product of the lime mixed in to neutralize

As research over the past two decades has shown, there are many viable uses for ash as a product. Because it exhibits the same engineering properties as sands, gravel, and clays, bottom ash performs well as an aggregate in cement, concrete, and asphalt (ASH 1989).

hazardous sulfuric acids. Calcium sulfate is also known as industrial gypsum, and so fly ash has been marketed as a substitute for gypsum in wallboard manufacturing (Ehrenfeld and Gertler 1997).

There are several constraints on the Resource Recovery Facility's potential to turn its ash from residue to product. The Supreme Court's 1994 interpretation of the Resource Conservation and Recovery Act (RCRA) requires facilities to test their municipal waste combustion ash as a potential characteristically hazardous waste. Companies around the country completed this testing, and found the bulk of ash safe for reuse (ASH 1996). While the Resource Recovery Facility will be legally required to test its own material, our team assumes that it will pass federal regulatory scrutiny as well.

The Connecticut Department of Environmental Protection's (DEP) requirements are a bit more problematic. Thus far the DEP has prevented the reuse of ash as aggregate due to end-of-life concerns. When construction or road materials are no longer in productive use, they are demolished, and either landfilled or reused. Tiny, breathable dust particles are swept into the atmosphere when the materials are demolished. The DEP is concerned that this uncontrollable dust, rich with heavy metals and dioxins, will be hazardous to human health (L. Hewett, personal communication). Strict labeling, planning, and recovery requirements may mitigate this concern. Ideally, the material would never be crumbled and sent to a landfill; instead, it would always be reused in another product. As long as the DEP is able to track this material throughout its life, it could be used in applications where any toxicity concern would not be a problem. This area is one that Connecticut's ash producers will have to work with the state government to resolve. While these concerns prevent current recycling efforts, our team's suggestions are based on the premise that these problems will be overcome.

Water Resources

Not surprisingly, all of the facilities surveyed use water for their operations. Uses vary from once-through non-contact cooling water to water consumed as an ingredient in industrial processes. All of the facilities except Cytec Industries receive water exclusively from the municipality. Cytec receives some water from the Town, but the majority comes from on-site wells and from the Quinnipiac River (see Figure 6).

Cytec has two primary discharges of water. Non-contact cooling water is discharged to the storm sewer and then flows to the Quinnipiac River. This combined flow represents on average 1 MGD. Cytec also operates an industrial wastewater treatment plant that discharges approximately 3.5 MGD directly to the Quinnipiac River. The entire 4.5 MGD from Cytec has the potential for being re-routed to the other companies in the Wallingford industrial area.

The planned new power station has a significant requirement for cooling water. The Pennsylvania Power and Light Company estimates it will need approximately 3 MGD to replace water that is evaporated from the power

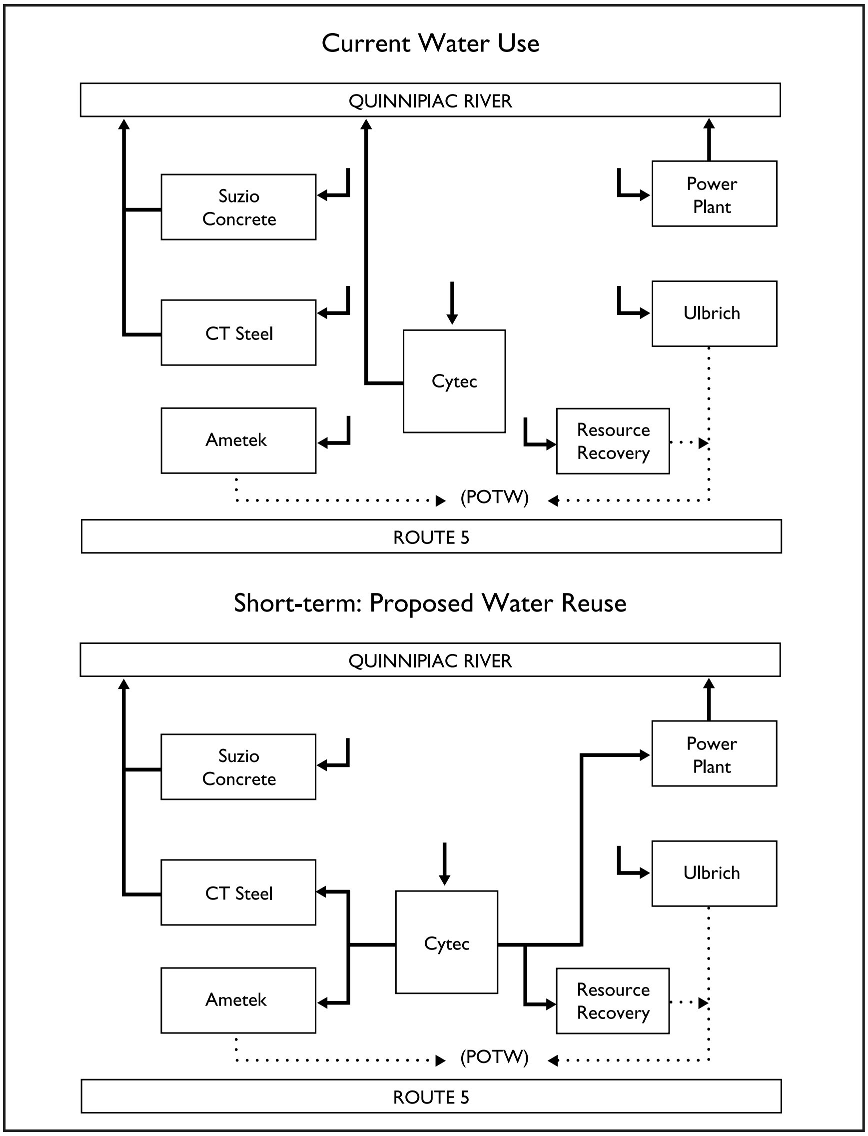

Figure 6 Current and Proposed Water Use

generation process and boiler blowdown. The project planners requested the use 3 MGD of the 6 MGD effluent from the Wallingford POTW, which is located only 500 feet from the proposed site of the power station. The DEP was not averse to the use of sanitary effluent for the power station, but they did not want to set the precedent of diverting water that would normally flow to the Quinnipiac River. The Quinnipiac River has low-flow conditions during some periods of the year; the DEP is concerned that diversion would further reduce the flow. Furthermore, setting a precedent for diverting flow from the Quinnipiac River may open the door for others to do the same. Therefore, our team has assessed not only water use, but also its impact on the flow of the Quinnipiac River.

The proposed power station is now tentatively planning to have its water demand supplied by a three mile pipeline from North Haven to Wallingford. The origin of this water is from non-drinking water wells that communicate with tidal reaches.

Industrial Campground

Trailer campgrounds are created to provide ultimate flexibility and ease of use to the customer. Campers can pull their recreational vehicles (RVs) into allotted sites and have all necessary services within reach, typically an electricity source, potable water and a sewage drain. Some even have a cable TV line.

Our team proposes the establishment of an "industrial campground" in Wallingford. This would involve identifying land in the target area for development with services that would be appropriate for medium to heavy industrial activity. The same services available at recreational campgrounds would be provided, such as electricity, potable water, and sewer. Additionally, gray water, steam, and specialty gases would be readily available.

Although the manufacturing facility of the future is unknown, there is a trend toward flexibility. Companies have to be quick to adjust to new trends in manufacturing processes as well as the desires of consumers, which can also move swiftly. Under these conditions, an industrial campground with pre-established services could allow existing firms to change processes with minimal delay, and could accommodate new businesses quickly.

This concept would not be limited only to services. Modular buildings would also be part of the planned industrial campground. These modular buildings would be configured for the incoming tenant, and reconfigured for successive tenants. Just as a single manufacturing facility may contain several products and product lines, the industrial campground could accommodate several companies within a single building. Walls within the shop area and office areas would be mobile to fit the needs of the client company.

By breaking down the paradigm of "one business, one building" and establishing a structure where businesses can be co-located under one roof, there can be a sharing of material inputs and outputs, and strategic purchasing for increasing the economies of scale. The sections that follow will be developed in concert with this concept of an industrial campground.

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SHORT-TERM SCENARIO: ONE TO THREE YEARS

Our proposed plan for the Wallingford EIP has been broken into three time frames. The first section focuses on modifications that are achievable within one to three years. Rather than confine the discussion only to ideas known to be economically viable, all suggestions have been included in the hopes of stimulating further thinking and perhaps overcoming barriers in creative ways. The difficulties of implementing these changes will be discussed in depth later.

For the near future, we suggest that the Wallingford EIP businesses take the following steps:

- Exchange high BTU value residues;
- Lay pipes for joint water, natural and industrial gas usage;
- Share transportation of scrap metal;
- Use sanitary sludge as a lawn fertilizer;
- Develop a formal Council on Industry and the Environment.

High BTU Value Resources

One of the prime materials identified for exchanges between facilities was the high BTU value residues produced by Ametek and Cytec. These materials, primarily comprised of oils and solvents, total 73,000 gallons each year and are currently sent off site for energy recovery. The Resource Recovery Facility uses

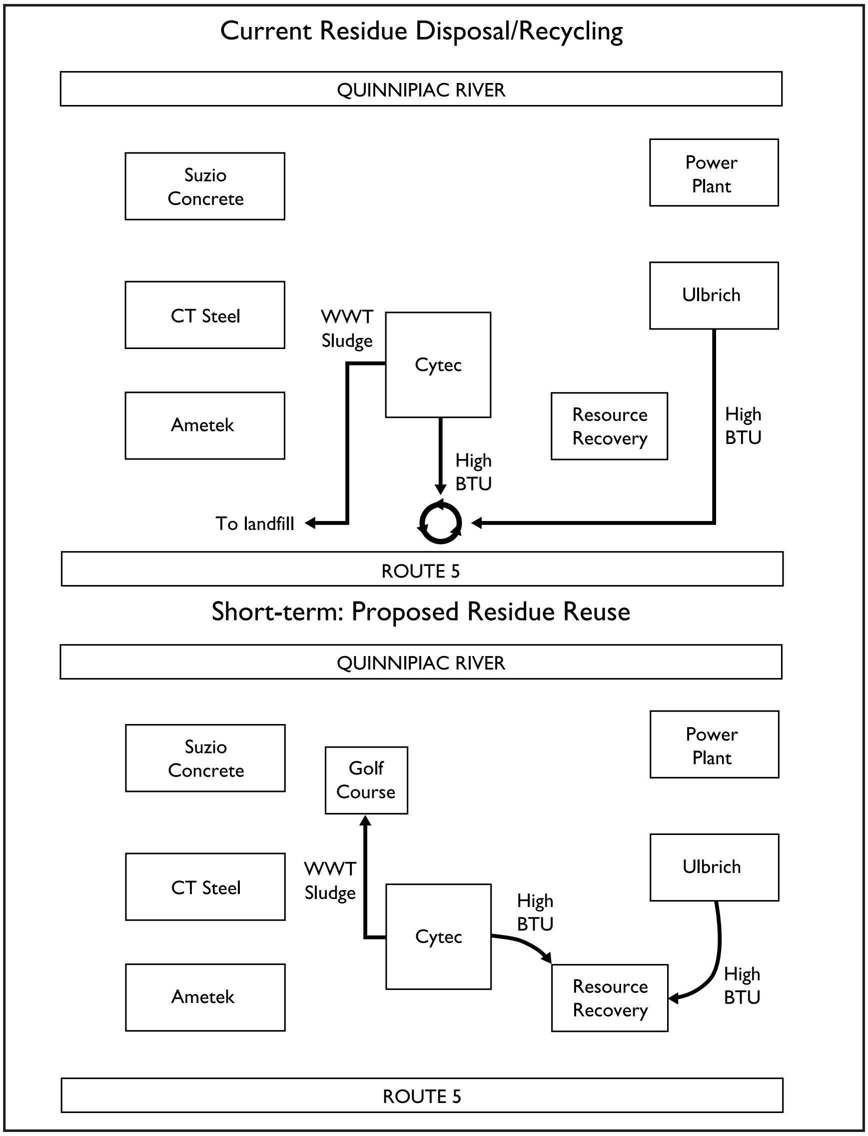

Figure 7 Current and Proposed Residue Flows

130,000 gallons of diesel fuel annually when it starts and stops the plant for maintenance checks. The recovery of the high BTU value residues in place of diesel fuel is proposed (see Appendix H). This exchange would reduce transportation costs and associated environmental harms, and begin the integration of the businesses into an EIP.

Industrial Gases

Four of the five businesses in the project have been identified as large users of industrial gases. While the Resource Recovery Facility does not use natural gas, it is the primary internal energy source for each of the others. Discussions have already commenced regarding the potential to install a natural gas pipeline that would service three of the plants-Cytec, Ametek, and Ulbrich. This transmission would be cheaper than comparable quantities purchased independently. Connecticut Steel is also a large user of natural gas, but due to the volume used has already worked out an efficient arrangement.

With the installation of a natural gas pipeline comes the opportunity to install several additional pipelines, at lower environmental and economic costs than if installed separately. Among these pipelines would be one or more designated for specialty gases, including argon, hydrogen, and nitrogen. Ametek, Cytec, and Ulbrich currently consume one or more of these gases in their production processes. The use of the pipelines will be discussed in the intermediate-term scenario. Laying the pipes will further the conversion of the site to an industrial campground – an area ready-made for industry. The additional infrastructure also supports goals expressed by the Town Planning and Zoning Commission and, due to the homogeneity of the area, would not impact any residential areas (POD Update 1993).

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Metals

Scrap metal is an important residue produced by the steel industries in the Wallingford area. Three industries, Ametek, Connecticut Steel, and Ulbrich, produce mill-generated scrap. The scrap, produced as raw steel, results from the cropping and shearing of metal plates while they pass from one process to another (Hogan 1998). Combined, these industries have an annual scrap metal output of 18 million pounds. Scrap metal is valuable and a large market exists for businesses whose only function is to recycle scrap metal.

Currently, there are no metal recycling facilities within Wallingford. Each industry is paying an outside company to remove and transport its scrap. Ametek ships its steel powders to its parent company in Pittsburgh. Ulbrich ships residue steel to the scrap yard in North Haven, and Connecticut Steel has its metal residues picked up by a scrap dealer in Waterbury. Sharing transportation is one way for Wallingford's metal industries to achieve cost savings in scrap metal removal.

The Wallingford area metal businesses could reduce their respective investments in excess inventory by integrating their shipments of scrap metal. By increasing the number and therefore the frequency of shipments, each can reduce its total quantity of metal in process. This may result in less space required for waste storage, freeing up valuable room on the shop floor. Both improvements could increase the cost effectiveness of managing work in progress inventory.

An even better situation would be to have the industries contract with a scrap metal dealer in Connecticut. There are over 70 scrap metal dealers within the state. In addition to cost savings, sharing transportation would benefit the environment through reduced pollutant emissions and less traffic on highways.

Sludge

A large residue stream from Cytec is sludge produced from the onsite wastewater treatment system. The sludge is incinerated onsite, using approximately 280,000 gallons of #2 fuel in the process. Due to the high concentrations of nitrogen, phosphorus, and potassium typically found in sludge from biological treatment processes, companies have found productive use for the material as a fertilizer (Manahan 1994). Given understandable concern over chemical constituents and public perception, Cytec has expressed a preference that the material be used for non-food purposes. For the near future, the most logical use of the sludge is as a fertilizer for the grounds around the EIP.

Beyond immediate EIP needs, the sludge could be used by the Town of Wallingford for municipal fertilizer needs. The Town has expressed a desire for recycled materials in repaved roadways. This interest in recycled materials could extend to using residual sludge as fertilizer along roadways, tree lawns, and parks (POD Update 1993). Additionally, Cytec may do well to market their sludge to local non-food agribusinesses. The material is well suited for fertilizing trees, flowers, or other ornamental plants. Other viable uses are as fertilizer for golf courses or as sodded landfill cover (see Figure 7). Should no suitable agribusinesses be present, the sludge could form the basis for a new company in the area.

Our team recommends the development of a formal Council on Industry and the Environment to further communication among the industries. Lowe et al. *(1997) cite the existence of a formal organizing structure as crucial to the development of an EIP.*

The Wallingford Council on Industry and the Environment

It is rumored that the success of the EIP in Kalundborg, Denmark, is partially attributable to the plant managers' involvement in the local Rotary Club. The Club provided an opportunity for casual talk about their companies, and linkages developed from these conversations. In Wallingford, several of the plant managers meet through the local emergency planning committee; still others visit at the engineering society meetings. Our team recommends the development of a formal Council on Industry and the Environment to further communication among the industries.

Lowe *et al.* (1997) cite the existence of a formal organizing structure as crucial to the development of an EIP. The Wallingford Council would be comprised of leaders from each industrial facility, in addition to municipal representatives and residents. Alongside several environmental goals, the Town of Wallingford identified the further expansion and development of industry as a key goal in its 1993 Plan of Development (POD Update 1993).

Participation on the Council will allow the municipality to direct and encourage the industrial development in coordination with its stated goals. By bringing all stakeholders together in one place, the Council will include many points of view as it develops a vision for the area. Initially the Council may serve as a forum for discussion of ongoing issues-the installation of a natural gas pipeline, or the use of water and wastewater in the area. As the companies develop greater trust and openness through the regular meetings of the Council, more issues can be tackled.

Water Resources

Using Cytec's wastewater streams, the immediate water needs of several nearby industries can be met (see Figure 6). Ametek, Connecticut Steel, and the Resource Recovery Facility can be supplied 220 gallons per day (GPD), 136,000 GPD and 250,000 GPD, respectively. It is proposed that pipelines be laid between Cytec and Connecticut Steel with a connection added for Ametek. For the Resource Recovery Facility, it may be feasible to pump the water through the steam pipe that was installed several years ago to supply steam from Resource Recovery to Cytec. By using the non-contact cooling water that Cytec generates, no water quality concerns should arise from this arrangement.

Our team believes this scenario represents a logical first step for the Wallingford EIP. The recommendations do not involve large investments of capital that have not already been explored by the partner companies. Instead, the scenario centers on taking a first step: building trust and openness to the idea of an EIP by meeting immediate needs. A successful first step will pave the way for more complex interactions in the future.

INTERMEDIATE SCENARIO: THREE TO FIVE YEARS

The focus of the intermediate-term scenario is the expansion of the Wallingford EIP to draw new businesses into the area. All of the recommended economic developments are connected to the current businesses via one or more material exchanges. An ash processor, wallboard manufacturer, and mini-mill all utilize residues from ongoing processes as raw inputs to their products. Other new businesses could produce the materials that could be used as raw inputs for current facilities: an industrial gas manufacturer would produce argon, hydrogen, and nitrogen to be used by Ametek and Ulbrich. The ideal new business is one that will use current residues to produce materials that can be used as inputs to another facility. An ash processor, using the Resource Recovery Facility's ash to make aggregate for Suzio Concrete, meets this requirement, as does a mini-mill. Developing these industries in the area will reduce transportation costs and integrate the facilities. While focusing on economic development, other suggestions regarding the role of the Council on Industry and the Environment and the use of water resources are also included. In the following three to five years, we recommend:

- Siting four new businesses in the Wallingford area:
  - an ash processor,
  - a wallboard manufacturer,
  - an industrial gas manufacturer, and
  - a mini-mill
- Using the Council on Industry and the Environment as a vehicle to examine linkages among industries and develop an EIP plan for the area;
- Using wastewater from the Wallingford POTW as cooling water in the planned combined cycle power plant;
- Developing a water credit trading scheme to mitigate diversions from the Quinnipiac River.

Ash

If the regulatory constraints on ash reuse can be overcome, the Resource Recovery Facility can control other potential problems in ash reuse. The characteristics and quality of the ash is one such issue. The current stream is a mixture of two residue types. Fly ash and bottom ash contribute different characteristics to the ultimate residue: bottom ash is a mixture of unburned hydrocarbons with chunks of metals and glass, while fly ash is predominantly heavy metals, calcium sulfate, unreacted lime, and particulate matter. If separated, the two streams would be purer in their characteristics, and consequently it may be easier to find markets for each.

Once separated, the streams may need to be purified further. Ash is often sieved to remove large objects and produce a finer product of similar size (ASH 1989). The two streams also contain large quantities of water, typically 25-30% by weight (ASH 1989). The water contributes to the weight, increasing hauling expenses, and creating a less desirable aggregate. Reducing the water content through drying would decrease hauling costs and increase marketability. Finally, the bottom ash should be processed to reduce metal content. Both ferrous and nonferrous metals are present, and if recovered, could provide an additional market product, while improving the purity of bottom ash for resale.

The ultimate goal of these two processes is to make the residue stream more viable as market products. While it would be possible to undertake the processes within the Resource Recovery Facility, it is also conceivable that a third party could process the ash for resale. In fact, the desire to purchase bottom ash through a processor for aggregate has been expressed by Suzio Concrete, although it indicated that it would need a separate storage silo for this material (see Figure 8). The intermediate ash processor would be another form of economic development in the Wallingford area.

The Resource Recovery Facility would benefit from reduced transportation and hauling costs, while Suzio would benefit from a local, reliable source of aggregate, and the Town of Wallingford would benefit from an increased tax base and more jobs. In addition to these economic benefits, the Town of

Wallingford would meet its goal of increasing the use of recycled materials by specifying the use of concrete with ash for future infrastructure needs (POD Update 1993). While the economic details of the proposed scenario are beyond the scope of this project, the potential benefits merit further consideration.

A second type of facility could be brought in to deal with Resource Recovery Facility's fly ash residue. In Kalundborg, Denmark, a wallboard manufacturer replaced virgin gypsum with fly ash-primarily calcium sulfate, or industrial gypsum-from the local coal-fired power plant (Ehrenfeld and Gertler 1997). This seems a viable option for the Resource Recovery Facility's fly ash as well. Should a wallboard manufacturer want the material processed before use in manufacturing, the ash processor described above could handle this task.

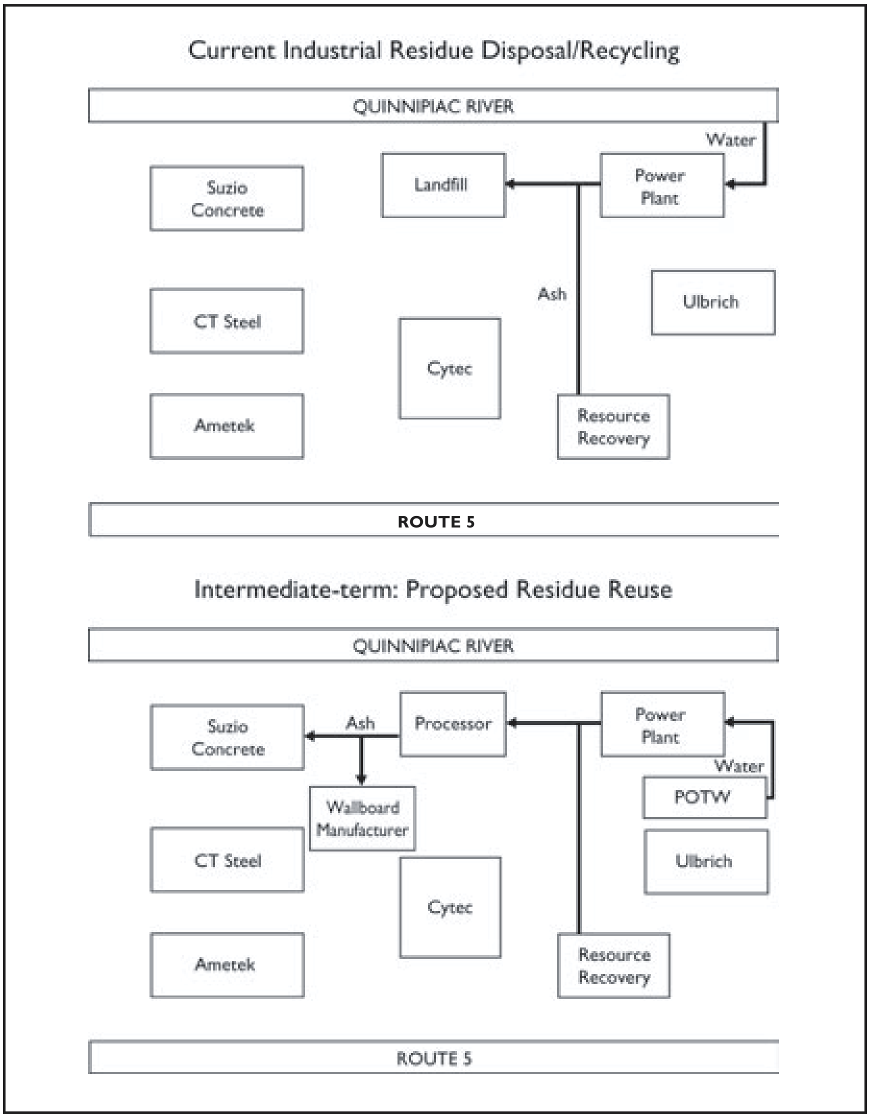

Figure 8 Current and Proposed Industrial Residue Flows I

Industrial Gases

The specialty gas pipeline recommended previously will come into use during this intermediate time frame. We recommend the siting of an industrial gas manufacturer in Wallingford as one of the new economic developments (see Figure 9). Ametek uses a combined total of 108 million cubic feet of hydrogen and nitrogen each year, while Ulbrich consumes argon, hydrogen, and nitrogen at a rate of 1.4 billion cubic feet per year. Cytec also uses some nitrogen, albeit at a lower rate than the other two. These gases are consumed as they are used to create a reducing environment to prevent oxidation of the metal surface during manufacture (Air Products 1999). Thus an industrial gas manufacturer could supply argon, nitrogen, and hydrogen to Ametek, Ulbrich, and Cytec via the pipelines. Filtering and purifying air readily withdraws pure argon, nitrogen, and oxygen (Universal Industrial Gases 1999).

Hydrogen, made through the catalytic conversion of steam and methane, could also be produced (Air Products 1999). With the siting of a gas manufacturing plant within the industrial park, the three companies would be freed from the costs of transporting and storing gases; instead, they could rely on the fresh, instantly delivered materials from the new manufacturer. This material would be distributed via a network of pipelines (as discussed in the industrial campground concept).

With the siting of a gas manufacturing plant within the industrial park, the three companies would be freed from the costs of transporting and storing gases; instead, they could rely on the fresh, instantly delivered materials from the new manufacturer.

Metals

As described in the short-term scenario section, scrap metal is currently being carried off site for recycling. Although sharing transportation costs of scrap metal removal provides a good short-term solution to cost reduction, the establishment of a mini-mill within Wallingford may prove to be even more economically beneficial. Mini-mills began to appear across the US after WWII, when plants shifted from open hearths to electric furnaces. Since then, this industry has rapidly expanded; there are over 50 mini-mills in the US operated by more than 31 companies (Hogan 1988).

There are several basic characteristics of a mini-mill. Originally, a mini-mill was considered to have 100,000 tons or less of raw steel capacity, while today some plants have a steel making capacity well over 1 million tons (Hogan 1988). The equipment consists of an electric furnace wholly dependent on scrap, a breakdown mill to reduce small ingots to billet size or a continuous caster that casts billets directly from molten steel, and a bar mill. The product line is usually restricted to concrete reinforcing bars, merchant bars, and in some cases, light structural shapes, such as small angles and channels. The original mills served a market usually within a 200- to 300-mile radius of the mill (Hogan 1988).

The operation and integration of a mini-mill within the EIP would be relatively simple. The raw material for the mill would be the scrap metal generated by the three steel industries (see Figure 9). The scrap metal would be melted by an electric furnace and refined into steel. The molten steel is poured into a ladle and discharged into a continuous caster. Most mini-mills cast billets that are reheated and rolled into final products on the bar mill.

The establishment of a mini-mill for scrap metal would substantially reduce transportation costs. Rather than trucking the scrap through three states, it could readily be delivered locally. In addition to reducing transportation costs, cost savings on raw materials would also result. Reprocessed metals could be used to supplement raw materials, thereby reducing the amount of virgin raw materials needed. The use of reprocessed metals in the manufacturing of products closes the loop for metal flows. All metal scrap is reused, preventing the need for disposal into a landfill. The scrap metal produced by the manufacturing process would be taken to the mini-mill, processed, and sent back to the factories to be used again in manufacturing.

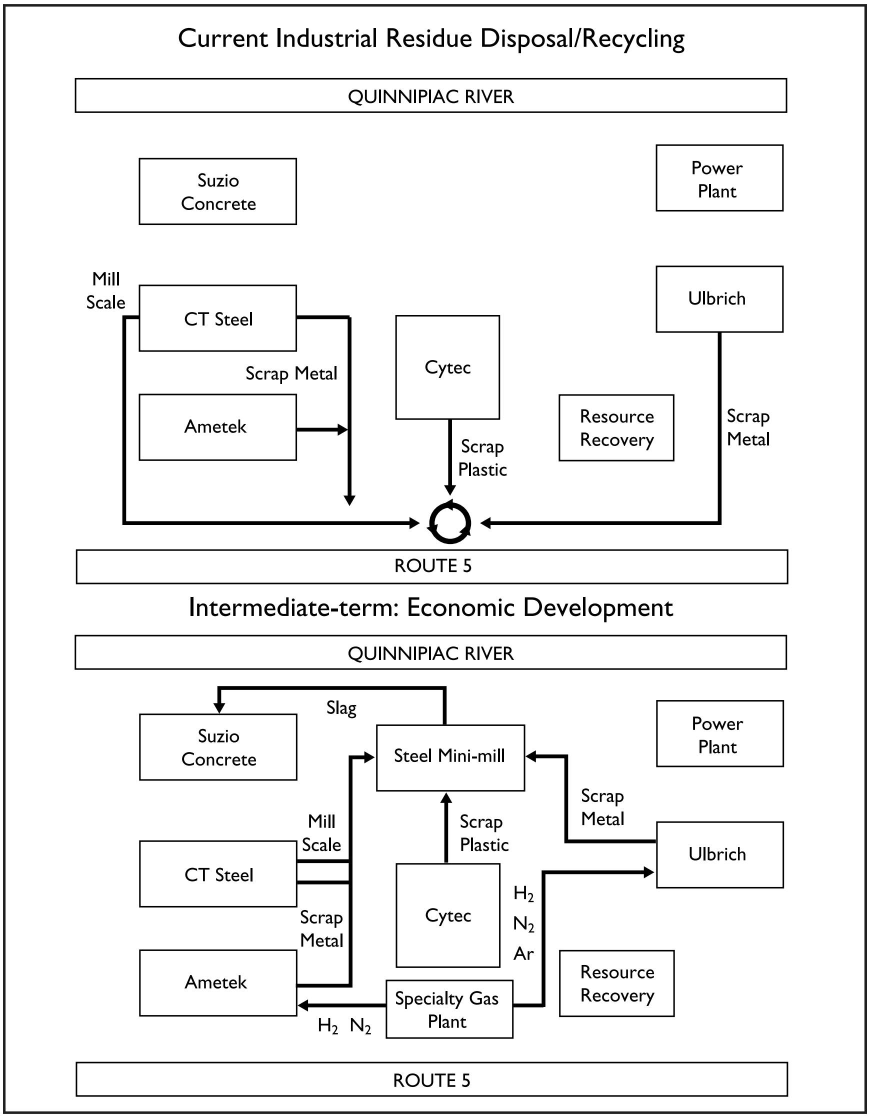

Figure 9 Current and Proposed Industrial Residue Flows II

The Wallingford Council on Industry and the Environment

In the intermediate-term scenario, the Wallingford Council on Industry and the Environment would play a leading role in the development of an EIP. Joint work on a natural gas pipeline and wastewater reuse could give way to more specific discussions of materials inflows and outflows. We were unable to identify a large number of residue exchanges between exisiting companies for several reasons. One primary reason was a concern over proprietary matters. As the companies work together through the Council and further understand the concept of an EIP, these proprietary concerns may be lessened. Another reason we were not able to find more linkages may have been the number of extremely similar companies – three of the five entities conduct metal reforming operations. These processes use similar materials, reducing the opportunity for unique exchanges among them. With the development of a Council, more industries will be involved, and a greater variety of materials will be available for exchanges.

In addition to examining the linkages between current industries, the Council is an ideal place to develop and implement a more holistic EIP plan for the area. For instance, the Council could recommend the types of industries it would like to see drawn to the Wallingford area, basing its recommendations on the material flows and resources already present. It could also suggest facility requirements; for example, new plants should exhibit a set level of energy efficiency, introduce no new consumptive uses of water, be located on brownfields, and demonstrate two or more links to current industries in the area. This type of development would take more care in implementation. Actual regulations would go beyond the scope of the Council, but simply having a group of people consciously focused on environmental issues could do much to pressure other industries to meet their suggestions, regardless of legal requirements. In this manner the Council provides an excellent forum for further developing the Wallingford EIP.

The extensive use of the waste treatment plant effluent is consistent with Wallingford's goal of water conservation (POD Update 1993).The use of this water would prevent the need for a pipeline to be installed from North Haven.

Water Resources

As the planned Pennsylvania Light and Power Company plant comes online during this intermediate time frame, our team proposes that its water needs be met by the effluent of the Wallingford POTW. The extensive use of the waste treatment plant effluent is consistent with Wallingford's goal of water conservation (POD Update 1993).

The use of this water would prevent the need for a pipeline to be installed from North Haven. Although diversion from the Quinnipiac River is still an issue, our team proposes a trading scheme to decrease the diversionary flows from the river. Anyone currently drawing water from the river would be given permits or credits for the amount of water that is not returned. The power station would be required to replace the water that it receives from the POTW with credits purchased from users within the watershed.

This recommendation is made on the assumption that it would be less expensive for other water users to reduce their consumption than to construct a three-mile pipeline. A trading scheme would also allow reusing water supplies instead of developing a virgin source. A full financial analysis will need to be conducted to determine if this assumption is correct.

The three-to-five year recommendations build upon steps suggested in the short-term scenario. Adding several new businesses will close the loop for particular materials, by processing the residue from one company to create input material for another. Perhaps it is unrealistic to assume these facilities will be sited and online within five years. The cost and scale of economy for particular issues also may make some recommendations impractical. By creating an ideal case scenario, creative thinking around these issues may be stimulated.

LONG-TERM SCENARIO: FIVE TO TEN YEARS

The final scenario proposed for the Wallingford EIP is more theoretical than the previous sections: if there were no restrictions, what are the preferred results? Our recommendations focus on three themes: researching methods to reduce the toxicity and volume of residue material, improving the appearance of the EIP, and integrating nature. These last two themes are interconnected: our recommendations highlight land uses that will enhance the visual appeal of the park while concurrently performing needed industrial functions and providing desirable social functions and wildlife habitat.

The final piece of this puzzle is the development of an industrial campground. This feature of the EIP will attract small and medium sized businesses that require short lead times for start up and extreme flexibility in their manufacturing processes.

In the next five to ten years, our team recommends that the Wallingford industrial park:

- Create a household hazardous waste recovery and recycling program;
- Mine the municipal solid waste landfill for metals;
- Research and implement programs to reduce the volumes of ash, industrial gases, and sludge in process;
- Convert the waste-to-energy plant to a cogeneration plant, selling both steam and electricity;
- Develop an aesthetics code, voluntary environmental initiatives, and shared service functions through the Council on Industry and the Environment;
- Build a canal to carry cooling water through the park;
- Extend planned trails through the area;
- Construct wetlands to treat wastewater.

Ash

In the long term, the Resource Recovery Facility should look at new ways of producing ash. There are two areas to be researched: first, methods to decrease hazardous characteristics of ash, and secondly, methods to decrease the volume of ash generated. The hazardous characteristics-high heavy metals and dioxin content in a readily breathable form-are the basis for the Connecticut DEP's concerns regarding reuse of fly and bottom ash. The initial separation, processing, and labeling steps recommended above may do much to combat these fears. Taking these steps further, the facility could control the types of materials burned.

Municipal solid waste typically does not contain many hazardous constituents, making it feasible to separate out the ones that are. One way to do this would be to implement an aggressive recycling program: the Resource Recovery Facility could serve as the momentum behind a household hazardous waste recovery plan. Such a program could target batteries, old aerosol and paint cans, and other items typically found in household waste, for appropriate reuse or disposal.

In addition to improving the quality of ash produced, a recycling program would educate local residents on environmental issues, strengthen the relationship between the city and the facility, and, of course, offer substantial environmental benefits by way of reduced materials use. Recycling programs may also present another opportunity for an entrepreneur to open a viable recycling business. Battery recycling could, for example, be extended to area businesses so as to gather the throughput necessary to support such an endeavor.

In addition to improving the quality of ash produced, a recycling program would educate local residents on environmental issues, strengthen the relationship between the city and the facility, and, of course, offer substantial environmental benefits by way of reduced materials use.

Along with decreasing the toxicity of the ash, the Resource Recovery Facility should look at ways to reduce the volume of ash generated. While these recommendations may make ash production viable as a market function, the ultimate truth is that ash is a byproduct: electricity is the facility's focus product. Any incineration methods that would reduce the ash generated would presumably recover more energy from the trash itself. The Energy Answers Corporation (EAC) has greatly increased energy recovery from solid waste by shredding the trash and then burning it in midair. Shredding improves the uniformity of the fuel, while midair incineration increases the surface area available for air-fuel contact, creating a thorough burn. Typical mass burn plants produce an ash that still contains 8% combustible material. The EAC's plant in Rochester, Massachusetts produces an ash containing less than 1.5% combustible material (EAC 1999). These methods need to be investigated more fully for their applicability to the Resource Recovery Facility. Given that they may need capital investments to complete, they are included in the Wallingford EIP's long-term scenario.

Industrial Gases

In the long run, our team recommends that all companies take a hard look at how they are using industrial gases. Are these methods necessary? Producing argon and nitrogen is a cryogenic process, demanding large amounts of energy to maintain cool temperatures (Universal Industrial Gases 1999). The steam/ methane reforming to obtain hydrogen also requires much energy to induce the high temperatures necessary for catalytic conversion (Air Products 1999). The companies could reduce their embedded energy budgets by reducing gas consumption. Could new methods be developed that do not require consumptive uses of gases? While the current procedures may be state of the art, technology is ever evolving. We recommend that decreasing the use of specialty gases remains high on the list of research and development topics.

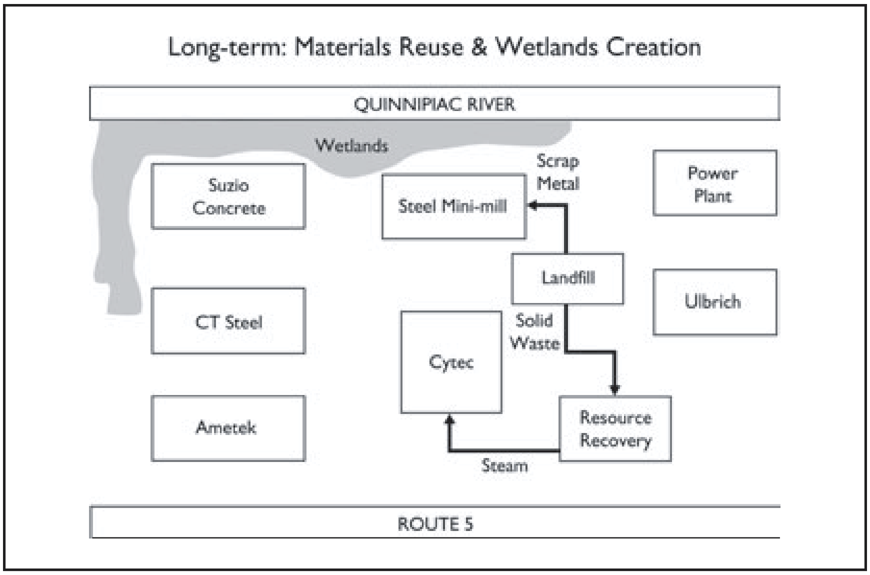

Figure 10 Long Term EIP Development Plans

Metal Recovery from the Landfill

Across the street from the Resource Recovery Facility, a municipal solid waste landfill is located within the bounds of the Wallingford EIP (see Figure 10).

The concentration of metals in Municipal Solid Waste (MSW) is such that it is economically feasible to mine them for use (National Research Council 1987). With the siting of a metals processing facility in the Wallingford EIP, this may be an opportunity to process scavenged metals from the landfill.

As the MSW is mined from the landfill, the non-metallic portion can be transported to the Resource Recovery Facility and burned for its energy content. Once the metal is processed, this additional source of raw material can be offered to the many firms in the park and in the region that produce metal products.

Steam

The typical power plant is a highly energy inefficient process, commonly achieving only 30% efficiency (Graedel *et al.*1998). Cogeneration is one way to greatly increase energy efficiency while simultaneously producing two marketable products: steam and electricity. Currently the Resource Recovery Facility produces electricity by incinerating trash. The heat from the fire converts water to steam, and the steam rotates a turbine, generating electricity. From there the steam is condensed via non-contact cooling water. The condensation process is one source of inefficiency in the process. A cogeneration plant eliminates this issue by intercepting the steam just after contact with the turbine. Rather than cool and condense it, the energy-rich steam is redirected to another user. Both steam and electricity are produced, and the overall energy efficiency of the plant increases to 80% (Graedel *et al.* 1998). Cooling water is no longer needed, though the increased use of water for steam may balance this reduced use.

In the past the Resource Recovery Facility has sold steam to Cytec, but ended this practice when the production of electricity became more viable. With the conversion to a cogeneration plant, the facility can sell both electricity and steam (see Figure 10). The 45,000 pounds per hour that Resource Recovery can produce will be a substantial portion of the 130,000 pounds per hour needed by Cytec.

The typical power plant is a highly energy inefficient process, commonly achieving only 30% efficiency (Graedel et al.*1998). Cogeneration is one way to greatly increase energy efficiency while simultaneously producing two marketable products: steam and electricity.*

Sludge

In the long term, Cytec should look at ways of reducing and refining sludge production. As a byproduct, it currently has only limited uses. Improving the quality of the sludge would greatly enhance its marketability and thus the range of options for reuse. The volume of sludge generated should be targeted for reduction. A lower volume of improved quality sludge can only mean increased efficiency in the wastewater treatment process, which is the ultimate goal.

The Wallingford Council on Industry and the Environment

In the long term, the Wallingford Council on Industry and the Environment would take a proactive role in local environmental issues. One of these issues would be aesthetic concerns. Currently the area is a mix of older manufacturing plants. A mutually agreed upon aesthetics code could recommend that all facilities develop indigenous plantings in open spaces facing public areas. Rooftop plantings hide an unpleasant roof while simultaneously reducing heating and cooling costs. Reduction of impervious surface can decrease potentially problematic runoff. Simple yet useful guidelines such as these could be the basis of a code focused on improving the area's aesthetic qualities.

In addition to tackling aesthetic concerns, the Council could develop agreements or competitions among industries. For instance, all industries could aim to reduce their energy consumption by 10% over a three-year period. Or the Council might offer an award to companies that use only renewable energy sources. Just as the U.S. EPA has developed a number of voluntary industry-government partnerships that increase productivity while benefiting the environment, the Council could be a local forum to do the same (EPA 1999).

Finally, the Council could complete the progress of an EIP by developing shared independent functions between entities. Such collective functions-such as a single parking lot, a carpool system, or joint regulatory compliance permits-would reduce the cost of each company providing their own, while further integrating the businesses. The reduction of costs affords each company the opportunity to increase the quality of service offered while concurrently increasing the scope of available resources. The trust and cooperation necessary to complete these joint functions should be in place at this later point in time. By moving from immediate concerns to more long-range functions, the Wallingford Council on Industry and the Environment could provide a forum for communication and visioning.

Water Resources

To further address aesthetics and water reuse issues, we recommend the construction of a watercourse that winds its way throughout the industrial area. This canal would eventually take all of the excess water from Cytec (including its effluent from the industrial waste treatment plant) and excess water from the Wallingford POTW. The canal would not only provide for scenic vistas within a rather bleak industrial area, but it would also provide a means of water conveyance to other parts of the industrial park. The canal would be of sufficient size to allow rapid dispersion of heat from cooling water, so that one company could discharge water to the course, and another could withdraw it shortly afterward. This scenic waterway could provide additional habitat for area wildlife and, as described below, could be lined with walkways or trails. Excess water flows and groundwater seepage would be directed to the Quinnipiac River.

Linking the planned Quinnipiac trail to the EIP watercourse would provide additional trails for the community and bolster the campus feel of the industrial area. Employees of the Wallingford industrial park could access the trails for exercise and could use the extensive network outside of the EIP for a means of cycling to work.

In addition, we propose that trails be installed that follow the cooling water waterway. A linear trail has been planned alongside the Quinnipiac River. A primary goal of the project is to enhance the aesthetic appreciation of the Quinnipiac River valley. The trail is proposed to extend the entire north-south distance of the Town of Wallingford and eventually connect to an existing trail in Cheshire and a proposed trail in Meriden. Although most of the trail is located on the west side of the Quinnipiac River, the trail crosses over to the east side just before it meets the southern border of town. This places the trail within the Wallingford industrial area.

Linking the planned Quinnipiac trail to the EIP watercourse would provide additional trails for the community and bolster the campus feel of the industrial area. Employees of the Wallingford industrial park could access the trails for exercise and could use the extensive network outside of the EIP for a means of cycling to work. Connecting this greenway to the other planned trails might also enable the participating businesses to access funding available for investments in alternative transportation improvements.

Wetlands

Large quantities of water are currently being used by the industries and discharged in the Quinnipiac River. Although some of this water is non-contact cooling water, wastewater that comes into contact with chemicals and metals is included in the discharge. This raises the question of how the industries are adversely impacting the quality of the Quinnipiac River and the surrounding ecosystem.

A possible long-term solution to this concern would be constructing wetlands (see Figure 10). Constructed wetlands are designed as a man-made complex of saturated substrates, emergent and submerged vegetation, animal life, and water, that stimulate natural wetlands for human use and benefits. The general components of a natural or constructed wetland include substrates with various rates of hydraulic conductivity, plants adapted to water-saturated anaerobic substrates, a water column, invertebrates and vertebrates, and an aerobic and anaerobic microbial population. Marshes with herbaceous emergent, and perhaps submerged, plants have the most promise for wastewater treatment (Hammer1991). The microbes found in wetlands use or alter contaminant substances to obtain nutrients and energy to live. The result is a reduction in the amount of contaminant present in the water.

Aesthetic concerns could also be addressed through a constructed wetland. A wetland creates a natural habitat for wildlife. New flora and fauna would soon arrive, making the appearance of the industrial buildings and their surrounding more pleasing.

Several studies have shown how constructed wetlands are an effective way to remove contaminants from water. In a study conducted by Weyerhaeuser, artificial marshes were effective at removing nitrogen (organic-N, ammonia, and nitrate), phosphorus, total organic carbon, and color from pulp mill effluents (Hammer 1991). Wetlands have also been shown to remove iron, manganese, and VOCs such as benzene from water (Hammer 1991). The construction of wetlands along the Quinnipiac River would allow microbes to feed off these same contaminants, reducing the overall amount entering the river.

A major limitation to constructed wetlands is the amount of land needed. This would not be a significant concern because there are several acres behind Cytec that are available for development. Aesthetic concerns could also be addressed through a constructed wetland. A wetland creates a natural habitat for wildlife. New flora and fauna would soon arrive, making the appearance of the industrial buildings and their surrounding more pleasing. Finally, creation of new wetlands might allow the EIP to receive benefits through organized wetlands banks that could fund the endeavor.

The issues tackled in the long-term scenario are clearly ones not needing immediate attention. As the priority issues are faced, however, the Wallingford EIP can focus on long-range sustainability concerns. By extending its reach from near-term matters to more overarching areas, Wallingford will become a leader in environmental management.

CONCLUSION: THE POTENTIAL OF THE WALLINGFORD EIP

Wallingford has two key ingredients that make it an ideal candidate for successful creation of an eco-industrial park: businesses with overlapping inputs and outputs, and attractive business amenities that can induce the siting of additional EIP partner industries. Perhaps as important, however, is the willingness of the existing businesses and Wallingford's Economic Development Coordinator to work with each another to achieve the potential efficiencies of an EIP arrangement. The next step of the project should be to investigate these proposed opportunities for their potential to produce favorable returns on the necessary investments of time and money.

The requisite scale of business partners will be an essential variable in evaluating the return on investment. The existing businesses are limited in the quantity of materials that they can provide to residue processors or purchase from new suppliers. It is questionable whether these transactions will be sufficient enough to merit the siting of a new facility. New facilities in Wallingford might operate at a scale that is not economically favorable to competitors in the sector.

In this regard, the existence of facilities and suppliers elsewhere serves as a barrier to the successful siting of new businesses in Wallingford, or any other medium-scale EIP. If these barriers cannot be overcome, the viability of EIP development may be dependent upon shrinking the minimum efficient scale of target industries. Conversely, EIPs might be most successful in areas that support a cluster of related industries en masse-such as wood finishing and furniture-making in North Carolina or auto-makers and suppliers in Detroit.

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As an example, the proposal to develop additional metal processing industries in Wallingford may suffer competitively from utilizing inputs at less than efficient scales. Although the mini-mill seems like part of the ideal solution to the question of metal residues disposal, there are still issues needing to be addressed. The major concern arises when looking at the economy of scale. The Wallingford EIP does not generate enough metal scrap and residue to sustain any of our proposed new industries. Currently, the Wallingford steel industry is producing only 18 million pounds per year, an amount far below what is needed to run a mini-mill. Nucor, a pioneer in mini-mill development, suggests a baseline of 400,000 to 500,000 tons per month of steel in order for a mini-mill to be economically feasible.

In addition to scrap metal quantity requirements, there are quality issues that need to be considered. The steel used by the mini-mill must be high quality with little or no copper content (Davis, personal communication). One solution to the problem of insufficient metal scrap volume would be to contact other steel manufacturers in the area (North Haven, Meriden) and to pool metal residues generated, by consolidating them in the Wallingford EIP. The problem with scrap metal quality is harder to resolve because of the different steel requirements of the industries.

Another issue that could pose a problem for the mini-mill idea is the quality of metal that each industry needs. Connecticut Steel, for example, uses plain carbon steel billets, with a carbon content between 0.04-0.7%. Because Ametek is producing electronic connectors, it has high quality standards for its raw material. The inclusion of Ametek may also be difficult due to the superior prices it receives internally for its recycled metals, due to their specialized formula. The other area steel businesses may have similar needs for specific raw material that may not fully be met if they were to use raw materials generated by any of the proposed new enterprises.

In spite of these constraints that may limit the potential to attract new industries to partner with the Wallingford EIP, our team believes that organizing the existing businesses around an EIP offers substantial, independent benefits. First, the businesses and community stand to benefit from the redirection of material flows in an EIP: businesses can profit from the cost reductions that emerge from more efficient use of raw materials and waste residues, while the whole community can expect to enjoy the fruits of improvement to the local environment.

Secondly, the Town of Wallingford can piggyback on the EIP investments of the businesses to create additional inducements for new business generation. Specifically, Wallingford can contribute to the laying of materials pipelines to create a ready-made industrial campground, as previously detailed. Such shared development will put firms and the government on the same side in promoting the project and reducing the costs for all participants.

Finally, promotion of virtual EIPs, creation of an industrial campground, and integration of existing industries into an ecological and aesthetic plan can serve as the central theme for future development in Wallingford. Such a unified vision could rightly be termed a sustainable development plan for Wallingford that would further integrate firms into the natural environment and the progressive community. This vision could establish Wallingford as a national model for sustainable development, differentiate it from other Northeastern neighbors, and offer the town a significant competitive advantage versus other communities.

ACKNOWLEDGEMENTS

The Wallingford Eco-Industrial Park team is thankful for the enthusiastic support received from the many contacts made in the Wallingford area. Not only was our team afforded site visits, but there were many follow up requests for information which received quick and complete responses. We thank the following organizations and their representatives:

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- Connecticut Steel: Gus Porter
- Cytec Industries: Charlie Cappannara
- Resource Recovery: Leon Plumer
- Suzio Concrete: Len Suzio

- Town of Wallingford: Don Roe, Ray Smith, Eric Kruger
- Ulbrich Specialty Steel Mill: Jerry Goudreau

Last, and certainly not least, our team is thankful for the guidance and many insights received from the Industrial Ecology course professors and support staff: Marian Chertow, William Ellis, Thomas Graedel, Reid Lifset, Janet Testa, and Robert Klee.

REFERENCES

Air Products. 1999. Information on gas manufacture. http://www.airproducts.com/gases/hydrgen.html

ASH 1989. *Proceedings of the Second International Conference on Municipal Solid Waste Combustor Ash Utilization.* Chesner, W.H. and F.J. Roethel, Eds. Resource Recovery Report, Chesner Engineering: Arlington, Virginia.

ASH 1993. *Proceedings of the Fifth International Conference on Municipal Solid Waste Combustor Ash Utilization.* Chesner, W.H. and F.J. Roethel, Eds. Resource Recovery Report, Chesner Engineering: Arlington, Virginia.

ASH 1996: *Proceedings of the Ninth International Conference on Municipal Solid Waste Combustor Ash Utilization.* Chesner, W.H., Ed. Resource Recovery Report, Chesner Engineering: Arlington, Virginia.

Burgert, Philip. 1996. A substitute for Oil: Plastic. *New Steel* 12: 83-4.

Davis, Linda. Personal conversation regarding the Nucor facility. April 1999.

EnergyAnswers Corporation (EAC). 1999. Brochures and reports. Albany, New York.

United States Environmental Protection Agency (EPA). 1999. http://www.epa.gov/partners/

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

Graedel, T.E., W.B. Ellis, and R.J. Lifset. 1998. *Environmental Aspects of Technological Society.* Yale University. Course materials

Hammer, D.A., Ed. 1989. *Constructed Wetlands for Wastewater Treatment.* Lewis Publishers: Chelsea, Michigan.

Hewitt, Larry. Personal conversation regarding DEP regulations. April 1999.

Kruger, Eric. Personal conversation regarding water utility operations. April 1999.

Lowe, E.A., and J. Warren. 1996. *The Source of Value.*

Lowe, E.A., J. Warren, and S. Moran. 1997. *Discovering Industrial Ecology: an Executive Briefing and Sourcebook.* Battelle Press: Columbus, Ohio.

Manahan, S.E. 1994. *Environmental Chemistry.* Lewis Publishers: Boca Raton, Florida.

Milone and MacBroom 1996. *Town of Wallingford, Water Supply Plan.* April 1996 (Revised July 1996).

National Research Council. 1987. Sherwood Plot.

Plan of Development. 1991. Town of Wallingford Planning and Zoning Commission: Wallingford, Connecticut.

Plan of Development Update 1993. Town of Wallingford Planning and Zoning Commission: Wallingford, Connecticut.

Stwertka, Albert and Eve 1978. *Steel Mill.* Franklin Watts: New York.

Universal Industrial Gases. 1999. http://www.uigi.com/Gaes/gases.html

Wallingford Economic Development Commission. 1999. *Wallingford…Works!*

APPENDIX A Ametek Specialty Metals

General

What are the products and services of this facility?

- Produce electronic connectors for electronic applications from metal powders; involves:
  1. continuous strip or sheet manufacturing involving high electricity input
  2. wire – either redrawn or from powders
  3. specialized powders for shaped components

Is production seasonal, continuous, or batch?

- components are batch, while all others are continuous

Inputs

Raw materials (type and quantity, purchase quantities, quality)

WATER	80,000 gallons per year of city water for cooling
ENERGY	Natural Gas: 40,000 cubic feet per year Electricity: 8 M kWh per year
METALS	Nickel: 1.5 MM pounds, Iron: 0.6 MM pounds, Copper: 0.5-0.25 MM pounds; Chrome alloys, other metals as low quantity additives
STEAM	None
OTHER	Gases: Nitrogen: 5 MM cubic feet per month, Hydrogen: 4 MM cubic feet per month; Lubricating oils, chlorinated solvents

Outputs

Types and quantities (include physical state, concentration, or purity)

- muffle gases are consumed in process
- metal wastes consist of 90-95% solids, plus some contaminated powders and cinder cakes
- recycled by parent in Pennsylvania because transportation relatively cheap in light of 25% price premium internally
- mineral-based lubricating oils (few thousand gallons annually)
- capture and distill solvents for degreasing; bottoms to recycler

Describe materials reuse or recycling currently being done (onsite and offsite)

- 15-20,000 lbs/year of copper/nickel/tin alloy with concentrations too high for traditional copper uses; again to Pittsburgh returned to powders
- nearly all other waste recycled
- send melt stock (off-specification, pure product) to Pittsburgh; recycle to powders
- 2% sold as scrap locally - degraded or contaminated to scrap dealer
- separate residues by alloy or chemical

Co-products and by-products produced

Would like to sell:

- iron and alluminide alloy powder; few thousand pounds per year
- off-specification but pure iron powder with high carbon content; 200,000 lbs/year

Other

Vacant areas or buildings

- no available space; have 18 acres limited by wetlands
- need space to expand (check nearby neighbors)

APPENDIX B Connecticut Steel

General

What are the products and services of this facility?

- produce plain carbon steel wire rod (2/3 are coils, 1/3 are added to reinforcing products)

Is production seasonal, continuous, or batch?

- continuous

What are the primary processes used on the site?

- rolling of steel billets to wire rod
- drawing of wire rod to wire
- melting of wire to reinforcing products

Inputs

Raw materials (type and quantity, purchase quantities, quality)

WATER	49 M gallons per year
ENERGY	Natural Gas: 270 cubic feet per year; Electricity: 32 M kWh per year
METALS	Plain carbon steel billets: 600 M lbs per year
STEAM	none
OTHER	small quantity of chemicals to treat water

Outputs

Types and quantities (include physical state, concentration, or purity)

- mill scale (6 M lbs/yr)
- scrap metal (15 M lbs/yr)

Describe materials reuse or recycling currently being done (onsite and offsite)

- scrap metal is picked up by a company in Waterbury that eventually recycles it in Pennsylvania

Co-products and by-products produced

- none

APPENDIX C Cytec Industries

General

What are the products and services of this facility?

- comprised of three groups: Cytec Industries (resins), A.C. Molding (thermosets) and Cyro Industries (thermoplastics)
- resins used in: paint, adhesives, water treatment chemicals, and paper products
- thermoset moldings for: dinnerware, electrical breakers, wallplates, and handles for kitchen utensils
- thermoplastic moldings for: battery cases, refrigerator trays, glasses, and medical devices

Is production seasonal, continuous, or batch?

- continuous

Inputs

Raw materials (type and quantity, purchase quantities, quality)

WATER	1.5 T gallons per year
ENERGY	Electricity: 48 M kWh per year
METALS	None
STEAM	130,000 lbs/hour
OTHER	Formaldehyde (44%), Ethanol, Methanol, Butanol, Iso butanol, Melamide, Natural gas, No. 6 fuel oil, Nitric acid, Acrilonitrile, Methyle methacrilate, Toluene, Ethyl acrylate, Urea, Acrlinitrile, Styrene

Outputs

Types and quantities (include physical state, concentration, or purity)

- waste water (non contact waste water: 365 M gallons/year; processed waste water: 1 T gallons/year)
- waste with BTU value (70,000 gallons/year)
- waste sludge (50 wet tons, 12% solids)
- ensolve (bromine base) cleaner
- oil with water (1,000 gallons/month)
- oily sand from filtration system (3,000 K/month)

Describe materials reuse or recycling currently being done (onsite and offsite)

- thermoplastic resins spilled are reused on-site
- waste plexiglas is sold for recovery
- waste solvents sent to cement kiln in New York
- plastic patty cake reintroduced or sold for sewer pipe manufacturing

Co-products and by-products produced

- milled powder currently being landfilled

Other

Vacant areas or buildings

- roughly 100 acres of vacant land between existing plant and river

Experience with purchasing or selling waste material

- steam experience with Waste to Energy, but discontinued because Resource Recovery switched to electrical generation

APPENDIX D Resource Recovery Facility

General

What are the products and services of this facility?

RRF is a waste-to-energy plant. It mass burns municipal solid waste (MSW) using the heat produced to run an electric generator, then the electricity is sold.

Is production seasonal, continuous, or batch?

- continuous; stopped twice per year for maintenance

What are the primary processes used on the site?

- MSW is sorted to remove large metal objects, which can cause problems in the burner
- MSW is hydraulically pushed into fire for burning
- heated gases rise, turning generator
- waste gas is sprayed with lime slurry before being released to the atmosphere
- fly ash mixed with burner's bottom ash, then landfilled

Inputs

Raw materials (type and quantity, purchase quantities, quality)

WATER	91,250,000 gallons/year
ENERGY	Diesel fuel: 120,000 gallons/year
METALS	none
STEAM	none
OTHER	MSW

Outputs

Types and quantities (include physical state, concentration, or purity)

- electricity (78,840 kwhr per year)
- steam (45,000 pounds/hour)
- ash (43,000 tons/year)

Describe materials reuse or recycling currently being done (onsite and offsite)

- none

Co-products and by-products produced

- none

APPENDIX E Ulbrich Specialty Strip Mill

General

What are the products and services of this facility?

- produce plain carbon steel wire rod (2/3 are coils, 1/3 are added to reinforcing products)

Is production seasonal, continuous, or batch?

- continuous

What are the primary processes used on the site?

- rolling of steel billets to wire rod
- annealing
- slitting
- cleaning (high pressure hot water, solvents)
- tool grinding

Inputs

Raw materials (type and quantity, purchase quantities, quality)

Water	12,000 gallons per year
Energy	Natural Gas: 6 M cubic feet per year; Electricity: 10 M kWh per year
Metals	Stainless and high temperature alloys: 20 M lbs per year
Steam	1,000 lbs per hour
Other	Gases: Nitrogen (10 M lbs per year), Hydrogen (65 M lbs per year), Argon (5 M lbs per year)

Outputs

Types and quantities (include physical state, concentration, or purity)

- oily cleaning water (4K gallons/week)
- grinding swarf (12 55-gallon drums/year)
- methylene chloride still bottons (1 55-gallon drum/year)
- ensolve (bromine base) cleaner
- oil with water (1,000 gallons/month)
- oily sand from filtration system (3,000 K/month)

Describe materials reuse or recycling currently being done (onsite and offsite)

- 3 M pounds/year of scrap metal is collected and shipped off-site for recycling

Co-products and by-products produced

- none

The Green Triangle of Boston, Massachusetts: An Eco-Industrial Cluster 1999

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ABSTRACT
This paper details a proposal for an eco-industrial park (EIP) in a section of Boston, Massachusetts, known as the Green Triangle. The paper reviews local efforts to revitalize the region by identifying common goals and leveraging the area's available resources. In particular, the paper focuses on four organizations that have formed a Green Triangle Coalition: the Arnold Arboretum, the Franklin Park Zoo, the Massachusetts Audubon Society, and Lena Park Community Development Corporation.

In the short term, the proposed EIP will include the four organizations listed above. Over time, we recommend that the EIP add a compost facility, to become the anchor, and other facilities, such as a centralized equipment facility and an organic farmers market. We have applied the principles of industrial ecology in the development of our proposal. As we will show, the application of industrial ecology principles to the study area creates a number of great opportunities for environmentally progressive economic development.

INTRODUCTION

The Green Triangle of Boston is an area with untapped potential that struggles with a poor image brought on by high unemployment and high crime rates. The eco-industrial park (EIP) could become a backbone for overall Green Triangle revitalization efforts. It would create opportunities for environmental and economic improvement by closing material flow loops, sharing commonly used resources, and developing synergistic exchanges. Our short-term plan focuses on integrating, planning, and formalizing relationships that have already begun to develop, as well as suggesting new, untapped opportunities for materials exchange. We also suggest firm-level approaches to conserving resources.

We next broaden material exchanges to include new, logical participants through the anchor-tenant model of an EIP. This anchor would create opportunities for new "tenant" facilities to become a part of the material exchange process. These are medium-term goals, requiring additional planning, possibly new infrastructure, and some alteration of current operational paradigms.

The aim of our long-term proposals is to increase connectedness among the EIP facilities. By adaptively reusing the existing infrastructure, and in some cases creating entirely new infrastructure, we hope to improve the efficiency of materials exchange.

The park will enhance profitability of existing enterprises by reducing input needs and adding value to residual streams. The enterprises envisioned will dovetail with existing plans for community revitalization by creating jobs and by fostering a sense of connectedness within the Green Triangle area.

BACKGROUND

South of the city of Boston, Massachusetts lies a string of parks and open spaces called the Emerald Necklace. The "Necklace," named for its elongated and gem-like shape, was designed by the noted American architect and planner Frederick Law Olmsted in the late 1800s. Running along a northeast to southwest axis, the string of six parks extends from the Boston Common downtown to Franklin Park in Roslindale and Roxbury. Jamaica Pond, which lies just north of the Arnold Arboretum, is one of the jewels of the Necklace. It was one of Boston's first drinking water reservoirs, and is now a beautiful recreational area where visitors can walk or rent a sailboat. Franklin Park lies in the south end of the Necklace, and at more than 500 acres, is the largest single piece of land in the Necklace. In Boston's heyday as an industrial center, wealthy neighborhoods with sprawling Victorian homes encircled the Necklace. But as Boston's economy changed during the post-war years, much of the city's wealth moved to the suburbs, shrinking the region's tax base. Today, many communities that border the Necklace struggle with issues of crime and unemployment.

The area surrounding the south end of the Necklace has been particularly hard hit by high unemployment and crime rates. The mean household income is 50% lower than the Boston Metropolitan Statistical Area. This area, now commonly referred to as the Green Triangle, includes four sections of Boston: Roxbury, Jamaica Plain, Dorchester, and Mattapan. The Green Triangle is the southernmost part of the Emerald Necklace, extending from the Arboretum to Franklin Park (see Figure 1).

In an effort to address the challenges faced by the Green Triangle, the nonprofit organization Boston Advisors, working with the Initiative for Competitive Inner Cities (ICIC), is leading a campaign to revitalize the region and develop the resources of the area. ICIC works with four organizations that have formed a Green Triangle Coalition to advance their common goals: the Arnold Arboretum, the Franklin Park Zoo, the Massachusetts Audubon Society, and Lena Park Community Development Corporation. These nonprofit organizations have identified recreation, conservation, education, and entertainment as their common missions, and recognize the region's potential as a resource for the greater Boston area. The group's economic development plans seek to attract more local residents and visitors to the area by making it a safe and fun place for families to spend an afternoon.

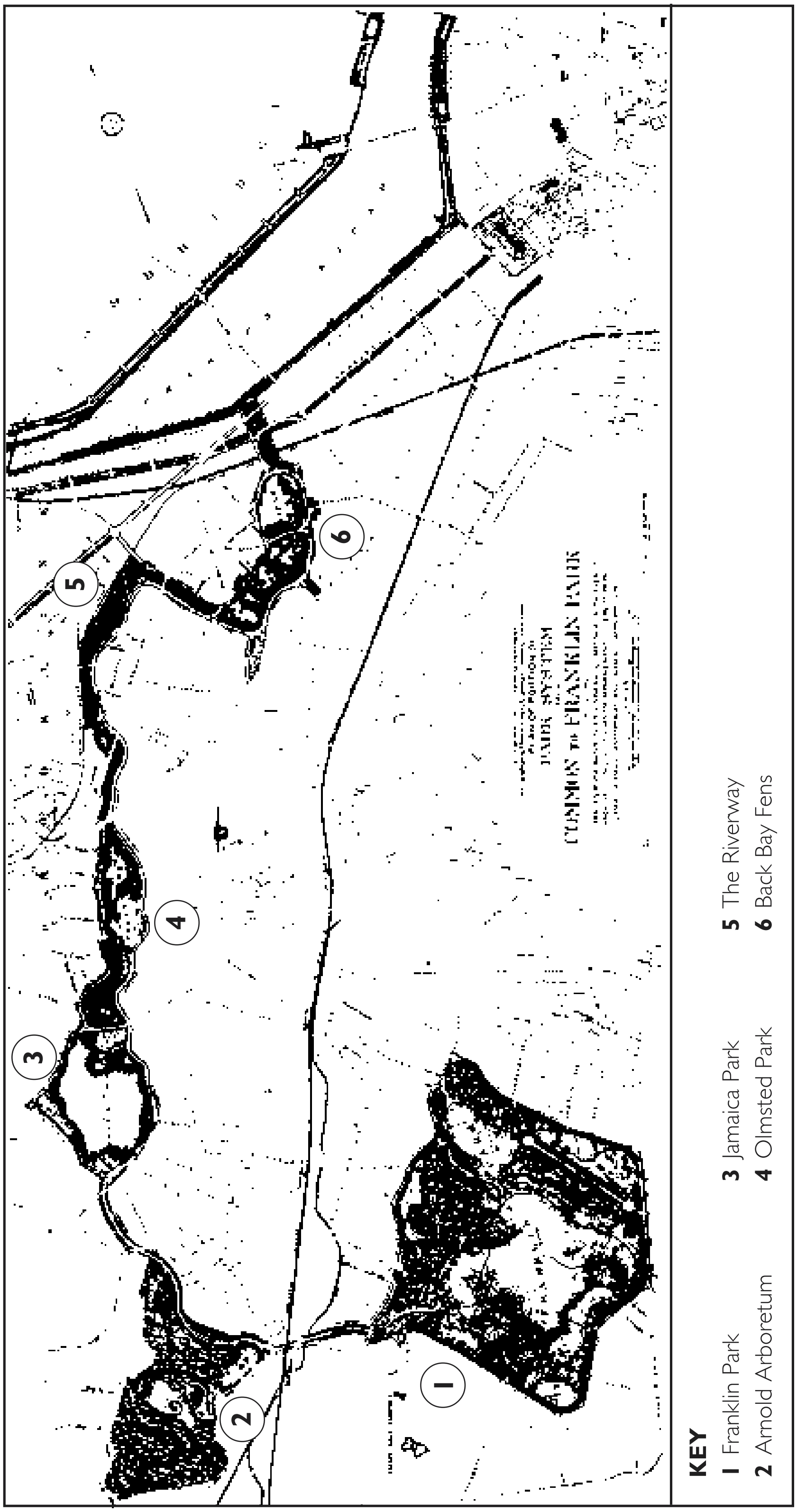

Figure 1 Map of the Emerald Necklace

The campaign to revitalize the Green Triangle area is supported by several consulting organizations, including the Boston Consulting Group and Anderson Consulting. These groups, along with Boston Advisers and ICIC, have devised a regional plan of action for the Green Triangle. The plan includes clean-up, signage, and a broader effort to help link the activities and goals of the Arboretum and the Zoo, as well as other entities in the area. In the words of its members:

> The Green Triangle is a coalition of not-for-profit organizations who share the common goal of strengthening and inter-linking Boston's natural and cultural assets located at the [south-] western end of the Emerald Necklace. The coalition is committed to increased coordination among its members (Boston Consulting Group 1998).

The Coalition has many challenges to overcome, including issues of accessibility and attractiveness. It also must overcome the public's perception that the Green Triangle is located in an unsafe neighborhood. Our proposals for an EIP will help the Coalition meet its goals of conservation, education, recreation, and entertainment, and its desire for economic development.

The past two years, however, have demonstrated the Zoo's potential to become a significant Boston area attraction and a financially viable entity. Revenues for 1998 were twice as large as 1996 revenues, while long-term plans project another doubling before 2006.

OVERVIEW OF MAJOR CO-LOCATED FACILITIES

The following section provides a brief overview of the facilities located in the Green Triangle. As seen in the map below, the Green Triangle possesses a plethora of natural and capital resources that can be attractive for economic revitalization, including the formulation of an eco-industrial park.

The Franklin Park Zoo

The Franklin Park Zoo occupies 78 acres of land, 55 of which are currently developed. Development consists of pathways for walking and driving, pens, barns, cages and other facilities to shelter animals, and buildings that house administrative and operational facilities. The Zoo is home to more than 800 animals that represent about 250 species (A.T. Kearney 1996). During 1998, the Zoo attracted approximately 170,000 visitors: 30% from Boston, 20% from the nearby towns of Braintree, Arlington, Brookline, and Needham. Ninety percent of these visitors traveled to the Zoo by car. Visitation provided slightly more than 1% of the Zoo's approximately $11million revenue in 1998. Major funding came from the state (63%) and corporate donors (22%)(Boston Consulting Group 1998).

The Zoo is currently leaving behind a period of instability. According to a 1996 A.T. Kearney report, "Decades of budget contractions, mismanagement, benign neglect and...undeserved negative publicity have brought the [Zoo] to the brink of failure"(A.T. Kearney 1996).

The past two years, however, have demonstrated the Zoo's potential to become a significant Boston area attraction and a financially viable entity. Revenues for 1998 were twice as large as 1996 revenues, while long-term plans project another doubling before 2006. To achieve this growth, the Zoo plans to significantly increase the size of its collections and further develop most of its property. Tentative plans call for including 150 additional species, developing 18 more acres of land, and increasing visitation by 250%.

The Arnold Arboretum

The Arnold Arboretum is a 265-acre botanical research and education institution owned and operated by Harvard University. It was founded in 1872 by the Arboretum's first director, Charles Sprague Sargent, who designed the grounds in collaboration with the landscape architect Frederick Law Olmsted, as part of Boston's Emerald Necklace park system. Today the Arboretum's collections include nearly 16,000 plants belonging to more than 4,000 taxa. Temperate zone species are the focus of the Arboretum. Trees and shrubs common to the northeast United States, including pine, spruce, oak, maple, rhododendron, and forsythia, are grown throughout the facility. Other species, including a small collection of tropical plants, are propagated in four greenhouses. Over 250,000 people visit the Arboretum each year.

The Arboretum is funded from three main sources: endowments maintained by Harvard University, grants, and memberships. In fiscal year 1997 the Arboretum received $4.1 million in endowment income, $1.4 million in grants, and $660,000 in membership dues, while expenses included $3 million for salaries, $1.4 million for services, and $1 million on supplies, equipment, and other operational outlays (The Arnold Arboretum 1997). Since the Arboretum is part of the city park system, roadway maintenance and repair is provided by the City of Boston.

The Massachusetts Audubon Society

The Massachusetts Audubon Society, an independent nonprofit organization founded in Boston in 1896, is the largest environmental organization in New England and one of the oldest conservation groups in the world (Massachusetts Audubon Society 1995). Through educational programs, land and wildlife conservation, research, and advocacy, the Massachusetts Audubon Society works to enable Massachusetts residents from all walks of life to experience the beauty of the natural world and to learn about and care for the ecological systems that sustain life on this planet.

The Massachusetts Audubon Society plans to develop a nature sanctuary on 65 acres of the 175-acre Boston State Hospital site, which includes Shattack Hospital. Its master plan includes: building and operating a 7,500 square foot environmental education center; preservation, restoration, and interpretation of the ecological systems on the property, which includes an eight-acre protected wetland; and management and enhancement of existing community gardens. An existing building located on the property will be renovated and converted into an on-site caretaker's facility. The sanctuary also will include two miles of paths, trails, and boardwalk, 0.25 miles of roadway/driveway, and parking for 60 cars with a 60-car overflow.

The Massachusetts Audubon Society plans to develop a nature sanctuary on 65 acres of the 175-acre Boston State Hospital site, which includes Shattack Hospital. Its master plan includes: building and operating a 7,500 square foot environmental education center; preservation, restoration, and interpretation of the ecological systems on the property; and management and enhancement of existing community gardens.

The Massachusetts Audubon Society has been working closely with other Green Triangle Coalition members to ensure that its site development plans complement the Coalition's overall goals. The Massachusetts Audubon Society intends to develop the property as a community resource that 1) provides exciting programming for children and adults; 2) preserves, restores, and interprets the site's valuable ecological systems; and 3) brings the revitalizing effects of an enhanced relationship with the natural world to residents in the surrounding neighborhoods and Boston as a whole. The organization hopes the sanctuary will be a fully utilized resource and a source of pride for the community, attracting positive interest in the neighborhood and offering residents opportunities to enrich their lives by learning from, interacting with, and helping to care for this abundant tract of natural beauty (Massachusetts Audubon Society 1995).

Lena Park Community Development Corporation

Lena Park Community Development Corporation is a social outreach organization, self-described as a multi-service center for minorities. Lena Park operates several programs, including housing, care for mentally retarded adults, day care, social service, care for senior citizens, youth sports, summer camp, general recreation, and youth development. Lena Park operates on a $2.7 million annual budget which covers housing rehabilitation for 236 subsidized housing units in 19 buildings in addition to staffing for the above listed programs.

The Cemetery attracts numerous visitors every year, many of whom come to view the old statues and other artwork spread throughout its grounds. Because of its location and its ability to attract visitors, it would make an interesting member of our eco-industrial park.

Area Cemeteries

The Forest Hills Cemetery sits on a large piece of land between the Boston State Hospital site and Franklin Park. The Cemetery attracts numerous visitors every year, many of whom come to view the old statues and other artwork spread throughout its grounds. Because of its location and its ability to attract visitors, it would make an interesting member of our eco-industrial park.

St. Michael's Cemetery, Mount Hope Cemetery, and Calvary Cemetery lie just south of Forest Hills. They all sit on much smaller pieces of land. At approximately 500 acres, the total size of these four cemeteries, however, rivals that of Franklin Park.

Franklin Park

At over 500 acres, Franklin Park is the largest park in the Emerald Necklace. It includes the 18-hole William Devin Golf Course, the oldest public golf course in the United States, and is host to major cross-country running events. The Park also is home to the Franklin Park Zoo, White Stadium, Scarborough Pond, and several baseball diamonds and tennis courts. All facilities except the golf course are maintained by the City of Boston's Department of Parks and Recreation.

Area Hospitals

Faulkner Hospital is located on Center Street on the western side of the Arnold Arboretum. Faulkner Hospital is a 130-bed community teaching hospital principally serving Jamaica Plain, Hyde Park, Roslindale, West Roxbury, and Dedham. Faulkner is one of Boston's major health care providers, offering complete medical, surgical, and psychiatric adult and inpatient care, as well as a full complement of emergency, ambulatory, and diagnostic services. Faulkner also boasts two nationally renowned Centers of Excellence that provide special services to specific populations: the Faulkner Sagoff Breast Imaging and Diagnostic Center, and the Faulkner Breast Center.

Other Facilities

Two other facilities that could play important roles in the development of an eco-industrial park lie within the Green Triangle. The Massachusetts State Laboratory sits in the northeastern corner of the Arnold Arboretum along Washington Street. In the past, the Arboretum has assisted the Laboratory with landscaping. The Arborway Yard is located on Arborway Drive between the Arboretum and Franklin Park. It is currently being used by the city as a bus depot, but the mayor has proposed building an ice rink and other recreational facilities there.

Abundant water is essential for Zoo operations. Water is consumed by and provides habitat for the Zoo animals, serves as a solvent for cleaning, and is the basis for the Zoo septic system, which includes toilets, fountains, and faucets.

EXISTING MATERIAL FLOWS

In the above section we briefly outlined the facilities located within the Green Triangle that are of interest to our project. In the following pages, the materials flows for each facility will be described in detail. We have placed primary focus on the Franklin Park Zoo, the Arnold Arboretum, and the Audubon Society.

Franklin Park Zoo

The following section addresses each of the major inputs required for Zoo operation. The intent is to present a current picture of materials consumption and energy use. Proposals for adapting these flows using the principles of industrial ecology follow in later discussion.

Water

Abundant water is essential for Zoo operations. Water is consumed by and provides habitat for the Zoo animals, serves as a solvent for cleaning, and is the basis for the Zoo septic system, which includes toilets, fountains, and faucets. All Zoo water is provided by the Boston Water and Sewage Commission (BWSC). Currently, very little water is re-circulated after its primary function has been served. All wastewater is returned to the BWSC for treatment. At this

Table 1 Zoo Water Usage

Estimated Monthly Consumption	3,601.5 gallons
Estimated/Adjusted Total Annual Consumption	48,980.4 gallons
Estimated Total Annual Cost	$132,247.10

time, the Zoo is charged on a per gallon basis for consumption, and also pays to treat as much water as it draws from the city system.

The Zoo is currently working to establish a dual metering system that would save money by recording the precise amount of water returned through the city system for treatment. Without that metering system, there is currently less incentive to find creative uses for water after its primary use.

One of the Zoo's primary attractions is the $26 million Tropical Rainforest. This freestanding, enclosed structure, completed in 1989, is home to more than 360 animals. The feat of mimicking a year-round tropical climate in the state of Massachusetts is accomplished through creative engineering and massive water use. The facility uses some 2.3 million gallons of water every month, or 64% of the Zoo's total water consumption. Although a large portion of this water is re-circulated and filtered, the Zoo pays to dispose of all of the water that it withdraws. The cost of water consumption and disposal for this facility alone is approximately $30,000 per month.

Planned facilities reflect greater concern for on-site water use. Barns that will house future collections of zebra and giraffe will be equipped with "living machines" that will treat water to be used for cleaning onsite and reduce the need for disposal.

The Zoo is currently working to establish a dual metering system that would save money by recording the precise amount of water returned through the city system for treatment. Without that metering system, there is currently less incentive to find creative uses for water after its primary use.

Food

Collectively, the Zoo's animals currently require more than 20 varieties of grain and a specialized horsemeat. Grain is purchased from Blue Seal, while the horsemeat product is shipped from a Nebraska supplier. Food for human visitors is provided through a fast food stand. Proposals include developing a push cart program that would allow local vendors to sell food in and around the Zoo area.

Energy

The exotic species housed at the Zoo depend on carefully regulated climates throughout the year. Heating needs are met predominantly through natural gas and oil. The main heating element is a natural gas boiler located next to the rainforest exhibit. Hot air from this boiler is fanned through the Zoo via a system of pipes. Electricity is used to power lights, in addition to fans and pumps that are critical for air and water circulation in many of the Zoo facilities. The Zoo also has a back-up diesel-fired generator on-site, which is used only during black-outs. In 1996, this generator on occasion failed to operate properly.

Trash

Trash currently is separated for recycling into high BTU waste that is suitable for incineration (vinyl, hard waste) and compostable organic material. An average of 60 cubic yards of trash is generated from the Zoo each week.

Manure

Zoo operators have recognized that manure is a valuable by-product of Zoo operations. For years, the Zoo has developed agreements with landscaping companies in the area to exchange manure for fees and/or services. An initial program that allowed on-site storage of excess manure was abandoned when the Zoo decided that it needed the space. The most recent arrangement has provided the Zoo with free landscaping services and compensation on a sliding scale in exchange for the Zoo's manure. The Zoo generates about 20 cubic yards of manure each week.

Plants

Maintaining flora both in and around animal homes is critical for the Zoo. Plants, shrubs, and trees are purchased from outside vendors while some mulch and wood chip needs are met through the Zoo's manure-for-services trade. The trading program does not, however, meet all of the Zoo's landscaping material needs. Soil, loam, sand, stone dust, and gravel are all purchased on an annual basis. Use of the chips and mulch provided through the manure swap is often limited because of aging requirements. The Zoo uses an Integrated Pest Management (IPM) system for pest management.

Zoo operators have recognized that manure is a valuable by-product of Zoo operations. For years, the Zoo has developed agreements with landscaping companies in the area to exchange manure for fees and/or services.

Equipment

The Zoo currently owns a tractor-style lawn mower, a front-end loader, a Bobcat, backhoe, tractor, pothole digger, and a sweeping truck. During the current phase of expansion, these vehicles are being used regularly.

Arnold Arboretum

For the purpose of identifying the major material flows at the 265-acre Arnold Arboretum, the facility will be divided into two areas. The first, grounds maintenance, includes the preservation and improvement of natural assets – trees, shrubs, lawns, soil, and streams – as well as the repair and upkeep of constructed stock such as trails, signs, and fences. The second is greenhouse operations. This encompasses not only plant propagation but also the operation of the four greenhouse facilities.

Grounds Maintenance

It is not surprising that grounds maintenance represents the major activity of the Arboretum. In terms of land area covered, materials used, and residues generated, maintenance of open-air assets is the facility's largest operation. This broad responsibility can be broken down into five areas:

- production of organic debris from pruning, tree removal and mowing;
- planting and flower bed care;
- pesticide and fertilizer application;
- watering; and
- upkeep of man-made capital stock including pathways, bridges, constructed water bodies, and signs.

A major source of organic debris is wood material collected during pruning, tree removal, and storm damage operations. Tree limbs may be removed because they represent a hazard or obstruction to visitors and workers. Pruning is also used as a horticultural management tool, since removing branches can promote the growth of trees with poor limb structures and allow additional sunlight to reach nearby species. Old or diseased trees, taken down because they are dangerous to people or other trees susceptible to disease, are another source of wood debris. Recently, the Arboretum supplemented its debris supply with “imports” from a neighbor, the Massachusetts State Laboratory, located on South Street. The debris generated there is brought back to the Arboretum.

Considerable wood debris is generated by storms, although the amount varies from year to year. A blizzard in April 1997, rated the most destructive storm to hit the Arboretum since the hurricane of 1938, affected over 1,700 trees, of which 400 were entirely removed and 1,300 pruned.

Table 2 shows the breakdown of the wood debris generated by the Arboretum in 1998. The input sources were almost entirely internal, though a small amount, approximately 20 cubic yards (cy), originated from the Massachusetts State Laboratory. The wood input is processed into four outputs: small junk wood, large junk wood, wood chips, and firewood. Junk wood is defined generally as wood that cannot be directly used by the Arboretum and is thus disposed of off-site. Small junk wood, including thorny brush, is undesirable as firewood or mulch, while large junk wood, including tree trunks, is too large for the Arboretum’s chipper and undesirable as firewood. Collected in twelve 30 cy dumpsters last year, the small junk wood is taken to “stump dumps” in the suburban towns of Tauton and Rayham, located twelve miles southwest of the Arboretum (it is unknown whether these dumps are landfills or recycling facilities). Logging trucks with estimated capacities of 30 cubic yards (cy) remove the large junk wood. According to the Arboretum’s Superintendent of Grounds, the trucks take the wood to facilities with “whole tree chippers” or to mills where they become wood product inputs. For both sizes of junk wood, the Arboretum pays the cost of removal.

Much of the wood debris, however, is reused by the Arboretum or its employees. 480 cy of firewood-grade material was cut last year and distributed to Arboretum employees. The firewood is grouped in cords which are 4.8 cy each. A two-step chipping process turns the 250 cy of debris gathered on-site and the 20 cy from the State Lab into high-quality mulch. A chipper brought into the field grinds the wood once, before a second machine known as a “tub chipper” turns the coarse chips into finer grade mulch. The mulch is applied to the bases of trees and to planting beds to prevent desiccation and insulate against cold weather.

Two other sources of organic debris are grass clippings and leaves. Grass clippings generated from the limited number of mowed acres are left on the ground unless the grass grows excessively high. Leaves are gathered in the fall in some areas, but most leaves are left uncollected and allowed to recycle back

Table 2 Organic Inputs and Outputs from Grounds Operations

THE ARNOLD ARBORETUM ORGANIC INPUTS AND OUTPUTS FROM GROUNDS OPERATIONS

INPUT				OUTPUT			
Material	**Internal or External**	**External Source Name**	**Quantity**	**Type**	**Processing**	**Use/Fate**	**Quantity (waste)**
Leaf litter	External	Harvard Yard	500	Compost	Deposited in composting yard	Applied as mulch	500
	Internal	n.a.	100	Compost	Deposited in composting yard	Applied as mulch	100
Wood debris	Internal	n.a.	360	Small junk wood	Collected in dumpsters	Disposed off-site[1]	(360)
	Internal	n.a.	60	Large junk wood	Loaded onto logging trucks	Processed off-site[2]	(60)
	Internal	n.a.	250	Wood chips	Chipped twice, stored in composting yard	Applied as mulch	250
	Internal	n.a.	480	Firewood	Cut and grouped in cords[3]	Given to employees	480
TOTAL			**1750**				**1330 (420)**

All figures in cubic yards.

[1] The Arboretum pays a garbage hauler to take the small junk wood to a "stump dump." It is not clear whether this material is re-used or simply fills up the dump.

[2] Again the Arboretum pays operators of logging trucks to remove the large junk wood which is processed in one of two ways: it is sent through a whole tree chipper and re-used as mulch and it is milled and later sold as wood products. IT MAKES NO SENSE THAT THE ARBORETUM PAYS FOR THIS. THE ARBORETUM HAS A VALUABLE RESOURCE.

[3] One cord is equal to 4.8 cubic yards.

into the soil. The Arboretum estimates that in 1998 they gathered about 100 cubic yards of leaves. In recent years, the Arboretum even began accepting leaves from Harvard Yard in Cambridge. Last year, 500 cubic yards were brought from the Harvard campus to the Arboretum, which allowed for a reduction in leaf disposal costs for Harvard and provided compostable material to the Arboretum.

Organic debris is collected at a composting yard on Bussey Street, located in the southwest portion of the Arboretum. It is about an acre in size and can hold up to 20,000 cubic yards of material. During the storm of 1997, the yard was filled to capacity, resulting in the disposal of some debris off-site. Soil and manure are also stored here, occupying roughly 20% of the space. The turnover time for the wood debris depends on the quantity and type of debris product needed, as well as the season. In the summer, well-ground debris, or mulch, is needed to prevent soil desiccation. The preparation of mulch does not require decomposition and thus, once ground, is ready for application. If allowed to decompose, wood debris can become a nutrient-rich fertilizer, but the preparation time is typically three months (Block and Goldstein 1998).

Over the past few years, the Arboretum has cut pesticide use by 85% through Integrated Pest Management (IPM) strategies that rely on natural predators to eliminate insect pests. Soil nutrient levels are supplemented through organic and synthetic fertilizers.

Processing organic residues is just one aspect of the Arboretum's grounds maintenance. Flower beds dot the landscape, and are maintained with new flowers and soil, and by weed removal. In all corners of the Arboretum, new trees and shrubs are planted during the spring and fall. Dead plant material is replaced, while new species are planted to better represent ecosystems, provide educational opportunities, and improve aesthetics.

Pesticides are used to reduce weed growth and insect damage. Annual quantities are unknown, but over the past few years, the Arboretum has cut pesticide use by 85% through Integrated Pest Management (IPM) strategies that rely on natural predators to eliminate insect pests. Soil nutrient levels are supplemented through organic and synthetic fertilizers. Last year, the grounds team applied 500 pounds of synthetic fertilizer to newly seeded lawns. Recent cooperation with the city mounted park ranger corps has resulted in the transfer of horse manure to the Arboretum, and last year approximately 100 cubic yards were exchanged between the two entities.

In the summer, watering is essential to keep drought-sensitive plants healthy, but since only ten of the 265 acres are irrigated, water use is low relative to the large size of the Arboretum. In the past, the Arboretum drew from City of Boston water supplies, but high chlorine levels forced a switch to its own sources. Two wells exist on the property, one with a 300 gallon capacity and the other with a 600 gallon limit. Along with greenhouse operations, grounds maintenance uses about two million gallons each year, at a cost of $20,000.

Throughout the Arboretum is infrastructure that requires upkeep. Pedestrian trails weave through the forests and over bridges that span streams and roads. In every nook, signs are found. On the trails, wood chips are spread to give soft footing and prevent ponding. Water bars – usually in the form of railroad ties – are installed to keep soil in place. As bridges age, their wooden planks, concrete, and stone must be replaced. New England winters make the lifetime of signs especially short. For the Arboretum to thrive, this infrastructure must be maintained, and this requires the regular purchase of materials.

Greenhouses

The Dana Greenhouses are a collection of four greenhouses located in the northwest corner of the Arboretum, near the Center Street Gate. The trees, shrubs, vines, and perennials grown here are used in two ways: they are transplanted on the Arboretum grounds, or sold to the public. Of the 7,800 plants removed from the greenhouses last year, 800 were planted in the Arboretum. Hardwood trees made up half of this total, while the other half is a mix of conifers, vines, and shrubs. In the Greenhouses' annual plant sale, about 3,500 trees, 2,800 shrubs, and 700 vines and perennials are purchased. Included in the sale are "surplus" plants from the in-house propagation. Because a certain mortality rate is expected, the number of plants initially grown exceeds the number of plants needed. When the actual mortality falls short of the expected mortality, a surplus results. Rather than incorporate the surplus into the planting plan for the grounds, the Arboretum sells the plants.

There are six primary inputs to the greenhouse operations. The first is soil. Approximately 25 cubic yards of "screened loam" is used each year. Added to this is a soil mixture that includes composted pine bark (65%), peat (25%), and rock minerals (10%). About 204 cubic yards of this soil mix is used each year. In the past, the greenhouse accepted compost from alternative sources, but high salt levels and weed seeds forced them to return to conventional suppliers that have the equipment to address these problems.

A second set of inputs is fertilizer, pesticides, and mulch. The greenhouses use about 100 pounds of nitrogen/phosphorous fertilizer each year. Unprocessed fertilizers, such as horse manure, are viewed with suspicion; they may contain salts, weed seeds, or other contaminants. Like the grounds maintenance unit, the greenhouses have dramatically reduced their use of chemical pesticides. The introduction of beneficial organisms as part of an IPM program addresses most pest management issues. Ground wood chips, or mulch, are provided free of charge by a local arborist company. The wood debris generated on the Arboretum grounds falls short of the demand from the greenhouses, so they have formed a beneficial partnership with an outside supplier. Unlike fertilizers and other composts, the quality constraints on mulch are less, perhaps due to its superficial application to plants.

A third input to the greenhouses is inorganic materials. Each year approximately 8,500 pots are used, 6,500 of which are purchased new, while the other 2,000 are reused. Another inorganic input is the plastic "bubble" material inserted between the exterior panes of the greenhouses. When filled with air, the plastic becomes an insulator with only marginal impacts on incoming solar radiation. Approximately 1,500 square feet of the material are used annually.

Water and energy represent the fourth input to the greenhouses. As discussed earlier, the Arboretum as a whole consumes about two million gallons of water per year. Energy use, namely heating, is a major concern for the greenhouses. When the sky is clear, solar energy raises the temperatures inside the greenhouses to the desired levels, generally around 70º Fahrenheit (F). In fact, sunny days make the greenhouses too warm. Temperature-controlled vents and fans release some of this heat to the external environment. Manual vents and shade cloth perform the same functions. But while high temperature is the problem during the day, cold is the problem at night, especially during the winter. It is estimated that the annual heating requirement for the four greenhouses – which total 6,240 square feet – is one million BTUs. Accounted for in this figure is the reduced temperature requirements (about 40º F) permitted in the winter in greenhouses with dormant species.

It is important to note that given the plants' high demand for carbon dioxide input, it was assumed that carbon dioxide was injected into the buildings. However, according to the greenhouse manager, no artificial sources of carbon dioxide are used.

Energy use, namely heating, is a major concern for the greenhouses It is estimated that the annual heating requirement for the four greenhouses – which total 6,240 square feet – is one million BTUs.

Massachusetts Audubon Society

While the Massachusetts Audubon Society has yet to break ground on the former Boston State Hospital site, the construction and future operations of the sanctuary play an important role in Green Triangle's potential eco-industrial park dynamics. The following discussion highlights material flows and other components of the development plan that influence our analysis of eco-industrial park implementation. The Massachusetts Audubon Society's vision for the sanctuary and its fit with the Green Triangle Coalition's goals is also discussed.

Development Plans

The planned environmental education center will provide programs offering a broad range of opportunities for children and adults from the community to learn about and interact with the natural world. Physical facilities will include a one-story main building (7,500 square feet), to be constructed of wood and other natural materials and designed "to be well integrated into the natural environment" (Massachusetts Audubon Society 1995). The center will consist of an assembly room, exhibit area, and gift shop. Office space within the center will provide space for program, administrative, and advocacy staff, headquarters for the Boston Education Project, as well as additional space that can be rented by other Boston environmental groups.

The Boston State Hospital Urban Gardens, currently occupying 350,000 square feet of the Massachusetts Audubon Society's property, are the oldest and one of the largest community gardens in Boston. The Massachusetts Audubon Society plans to renovate and oversee maintenance of the gardens as part of its overall development scheme. In cooperation with gardeners, the Massachusetts Audubon Society will improve the layout of the gardens, adding two storage sheds for tools and materials (375 square feet each) and walking paths. Renovation plans also include the construction of raised and other special garden beds designed for the disabled and elderly. In addition, the Massachusetts Audubon Society plans to address the gardens' critical issues of water use and cost distribution by installing a series of faucets that can monitor usage.

Aside from one structure that will be renovated and operated as a caretaker's facility, the Massachusetts Audubon Society has shown no interest in other buildings currently occupying the site. The State of Massachusetts is responsible for the removal of all unwanted buildings, structures, hazardous wastes, and other specifically identified materials on the site. There is no indication from the Massachusetts Audubon Society's master plan of a proactive effort to re-use materials from the demolition of old buildings and roads on the property. In addition, while natural buffers have been identified as part of the development plan, there is no indication that the Massachusetts Audubon Society will incorporate other design-for-environment principles into its development plan.

The Massachusetts Audubon Society has been working closely with other Green Triangle Coalition members to ensure that its development plans for the site complement the coalition's overall development goals as well as priorities identified by surrounding communities.

Vision for the Site

The Massachusetts Audubon Society has been working closely with other Green Triangle Coalition members to ensure that its development plans for the site complement the coalition's overall development goals as well as priorities identified by surrounding communities. Residents in the area have stressed a need for protection and enjoyment of open space, employment and job training programs, and environmental education.

The Massachusetts Audubon Society's plans are instrumental in advancing the Green Triangle Coalition's goal of increased environmental education. When complete, the environmental education center and wildlife sanctuary will be uniquely situated to serve as a major resource to Boston's public schools, and will be the headquarters for the Massachusetts Audubon Society's Boston Education Project. An estimated 48 elementary and high schools with over 23,000 students are located within two miles of the site. This represents almost 40% of Boston's public schools and generally defines the initial service area for the site.

Funding

Massachusetts Audubon Society expects to raise approximately $6 million from individuals, corporations, and foundations to cover expenses associated with the project, as well as provide an adequate, permanent endowment for the staff and site operations. The Massachusetts Audubon Society will not have to charge entrance fees or rely on increased visitation to maintain and grow operations over time. This is an important factor to consider in evaluating options and constraints for eco-industrial park development.

Area Cemeteries

The materials in the cemetery of interest to our proposal for an eco-industrial park are grass clippings and organic debris, including leaves and other yard waste. The usefulness of these residuals will become evident in the discussion of our medium-term proposal.

Area Hospitals

Of primary interest from the area hospitals are food waste and organic debris from landscaping activities. The usefulness of these residuals also will become evident in the discussion of our medium-term proposal.

ECO-INDUSTRIAL PARK PROPOSAL

Our recommendations for the development of an eco-industrial park are divided into short, medium, and long-term objectives. We conceptualize the breaks in the time periods as follows:

- **Short Term:** goals that can be reached using existing practices and resources. The short-term effort consists of bringing together facilities that have had some communication in the past.
- **Medium Term:** proposals requiring additional planning, possibly new infrastructure, and some alteration of current operational paradigms. Involves broadening materials exchanges to include new participants.
- **Long Term:** involves fundamental redesign of infrastructure, rethinking of roles, relationships, and technologies in the process of development. Builds on linkages throughout the area.

Our focus is on integrating, planning, and formalizing relationships that have already begun to develop, as well as suggesting and introducing new and untapped opportunities for materials exchange given current resource availability.

Short Term

This time frame includes activities that can be undertaken immediately. In some cases, the materials that we propose trading are already exchanged in some form. Our focus is on integrating, planning, and formalizing relationships that have already begun to develop, as well as suggesting and introducing new and untapped opportunities for materials exchange given current resource availability. Before addressing opportunities for exchange of materials between firms, it is important to focus on the efficiency of resource use within each entity.

Opportunities for the Zoo include reducing water use and disposal and capturing more value from its manure waste stream. The Arboretum should also focus on residual stream value, in addition to realizing value from slight changes in operating procedures. Because the Audubon site is currently under development, we exclude consideration of its general operations from this short-term section. However, we do recommend ways in which materials used and generated during construction activities can be captured. Interaction between these facilities forms the basis for our medium and long-term strategies.

The Zoo can take advantage of net metering immediately. Net metering entails installing additional meters that monitor water return to the city system.

The additional metering allows the user to benefit from its own "treatment" of city water by adjusting disposal charges to reflect only the amount disposed. Current systems at the Zoo levy disposal charges equal to the amount of water that is withdrawn. Because of water lost through evaporation from the duck pond and other sites, water that runs off directly to the ground, and water that is consumed, charges grossly overstate the actual amount of water the Zoo sends back for treatment. Setting up a net metering system is simple, and should immediately result in cost savings for the Zoo.

From an industrial ecology perspective, however, net metering accomplishes a more important goal. This goal is to encourage more on-site treatment of waste streams. A good example of effective on-site water treatment is the Living Machine currently under development for treating runoff from the zebra and giraffe barns (a Living Machine is a waste-water treatment system that uses a series of tanks filled with plants, algae, and bacteria to break down waste naturally, without chemicals). Without net metering, the water treated in these systems would be charged for treatment by the city. Net metering should inspire a search for additional opportunities for living machines. In the short term, as the Zoo plans for expansion of its facilities and development of additional areas, incorporating living machines should be a priority. The Zoo should evaluate the possibility of having larger, more centralized "machines" that could become exhibits unto themselves. The Zoo's mission is to put natural ecosystems and their inhabitants on display. The living machine is an interesting bridge between the human and natural world.

Eco-efficient designs often have short pay-back periods. Efficient lighting can create positive returns within two years.

Another input that should be given careful consideration as the Zoo expands its facilities is energy. Eco-efficient designs often have short pay-back periods. Efficient lighting can create positive returns within two years. Facilities should be designed such that any excess heat is funneled back to a productive use such as heating another facility, keeping ice off watering troughs or keeping rocks in the lion dens warm.

While the Zoo has been leveraging returns from its manure for some time, we suggest a two-pronged approach to capture more value from this critical residual stream. An important concept to be addressed in the medium term section involves the creation of a new entity to manage this waste. In the short-term, however, the Zoo should consider packaging manure for sale directly to its visitors for use as a fertilizer. This concept has been pioneered and proven successful by the ZooDoo company of Memphis, TN.[1] One option would be to contract directly with the existing operation. Benefits would include capturing ZooDoo's established brand name and web space. Our recommendation, however, is for the Zoo to develop its own program, keeping material flows and financial benefits local.

[1](1-800-I-LUV-DOO) Company did not return inquiries as to method for establishing a business relationship.

Currently, the Arboretum grows many more trees and plants than it needs on an annual basis. Most of these plants are sold during its annual plant sale; others are given away. This plant growing program leads to two short-term possibilities for improvement. First, every year, 8,500 plastic pots are used in the program, 2,000 of which are returned. Resource consumption could be lowered by increasing the rate of pot return. This could be accomplished by levying a pot deposit on top of each plant sale. This program would be extremely cost effective, reducing expenditures on new pots, and increasing revenues through unredeemed deposits. An important consideration in stimulating pot return is the environmental consequences embedded in the return action. Returning pots might increase fuel consumption (though it seems likely that Arboretum visitors would return pots during a trip they might have taken anyway) and it may be that pot purchasers individually put their pots to good use. Further study is needed to determine whether this program would yield net positive environmental and economic results.

The second idea generated by the Arboretum's plant sale represents the first material trade suggestion. The Arboretum has demonstrated that it has excess capacity in its growing operation. We believe that appropriate planning for this capacity would enable the Arboretum to share its excess plants with the Zoo. If additional capacity were needed, it is likely that the Arboretum could accomplish the expansion at lower cost than the Zoo currently incurs when it purchases plants for landscaping and animal habitat. An effective trading program would require advance planning, as the Zoo develops new land and as the Arboretum allocates growing capacity. This joint planning effort is the first step toward broadening the cooperative relationship between these entities. Regular contact between the organizations will enable discussion of other potential synergies. Potential partnering opportunities include joint purchases of material inputs such as sand, loam, and gravel. Joint purchases that capture economies of scale will be cost effective, and may yield environmental benefits through a decreased reliance on transportation.

The Arboretum has demonstrated that it has excess capacity in its growing operation. We believe that appropriate planning for this capacity would enable the Arboretum to share its excess plants with the Zoo.

As noted above, it is the responsibility of the state to remove all unwanted buildings from the State Hospital Site where the new Audubon Facility is currently under construction. Most of these buildings are made of brick and concrete. Crushed brick is an excellent source of path material, while crushed concrete may be useful as road fill. Because the Zoo is in an expansion phase, and the Arboretum requires trail maintenance, both of these materials may have some value and should be exploited in the short term.

A final short-term activity that leverages joint resources and meets a variety of objectives is to build existing education and recreation programs in the area jointly. Instead of a Lena Park Summer Camp, children could come to the Green Triangle for a summer experience that includes activities and learning at each of the facilities. Introducing children to the notion that facilities in an area are inter-linked could be an effective way to build support for the eco-industrial effort. Children may also generate new ideas about how resources can be shared.

Medium Term

The previous section introduced potential material exchanges among Green Triangle organizations, given existing practices and resource constraints. This section describes our strategy for enhancing these short-term opportunities, and for creating new opportunities for exchanges.

To broaden the scope of the eco-industrial park, we first looked at constraints on material exchange opportunities. The following are problems inherent in the short-term proposals for the Green Triangle:

- **Quality of materials exchanged.** The Arboretum has had quality issues with shipments of organic material. Past exchange programs with municipalities often resulted in unusable materials containing salt, weed seeds, or other contaminants.
- **Specialization in operations.** Certain elements of organizations' operations require specialized resources. For example, the Arboretum has specific requirements for the types of materials they can apply to plantings and landscaping. The Zoo requires special foods for its animals, and requires habitat-specific plants for exhibits.
- **Timing of materials exchanges.** Many materials with potential for exchange are available only during short windows of time, requiring rapid coordination and assessment of demand. For example, the Arboretum has a variable supply of excess plants at the end of the growing season that must be planted quickly to be used. On the demand side, input material demands vary due to seasonal needs.
- **Physical capacity constraints.** Many Green Triangle organizations, including the Arboretum and the Zoo, are limited in the expansion of operations beyond currently planned development. The Zoo formerly contracted with a company to exchange manure for fees and services. The Zoo was forced to buy out of that contract to reclaim land that had been used for temporary storage of the manure. The Zoo's on-site storage capacity is currently limited to one dumpster dedicated to manure and clippings. The Arboretum has a one acre facility for storing organic debris. Future expansion of organic material exchanges will require off-site storage of residuals.
- **Scale constraints.** Given the relatively small quantities of material involved, costs of developing infrastructure to support trades may in some cases be prohibitive.

An industrial ecology perspective includes an examination of the industrial system within the context of a natural system. We looked beyond the current actors in the short-term materials exchange process, and identified facilities such as hospitals, cemeteries, and the Franklin Park, which offered new opportunities without barriers such as quality concerns.

An industrial ecology perspective includes an examination of the industrial system within the context of a natural system. The advantage of this perspective is that potential opportunities are presented outside traditional bounds. We looked beyond the current actors in the short-term materials exchange process, and identified facilities such as hospitals, cemeteries, and the Franklin Park, which offered new opportunities without barriers such as quality concerns.

Anchor Proposal: Composting Facility

We propose as a possible solution to system constraints the development of an anchor facility. As described by Chertow's anchor-tenant model of an eco-industrial park, an anchor is a centralizing mechanism that can provide the increased scale and quality control necessary for system expansion.

Since organic residuals dominate the input and output cycles, a modern composting facility would be a powerful anchor. The composting facility would enable Green Triangle members to better coordinate and centralize the movement of organic residuals. The facility would convert organic residuals into mulch, fertilizer, wood chips, and other products that could be redistributed to Green Triangle members. Manure from the Zoo, for example, could be delivered to the site as an input to the production of mulch and fertilizers.

Since organic residuals dominate the input and output cycles, a modern composting facility would be a powerful anchor. The composting facility would enable Green Triangle members to better coordinate and centralize the movement of organic residuals.

Such a facility would enhance short-term opportunities for exchange by overcoming factors inhibiting material exchange in the present state. The composting facility could offer a wider variety of mulches and fertilizers that cater to the quality and timing specifications of the Arnold Arboretum. A composting facility would have adequate storage capacity to overcome production problems caused by seasonal fluctuations in material inputs. Increased inventory also would more capably handle variations in demand among consumers of composting products. The facility would have the necessary equipment and capacity to incorporate junk wood from the Arboretum that is currently disposed of off-site. Not only would this increase the flow of residuals, but it also would eliminate off-site transportation and disposal costs.

Perhaps most importantly, the increased scale and scope of operations generated through the composting facility would create new cost-effective exchange opportunities. A composting facility would expand the types of materials exchanged, enabling other area facilities to enter the materials flow cycle. For example, hospitals in the area, as well as restaurants and concession stands that are planned for development, could contribute food residuals. A composting venture run by the Lower East Side Ecology Center (LESEC) in Manhattan processes restaurant residuals, including soiled paper towels. The success of this effort has prompted LESEC to look to expand collection from generators to include a cafeteria and green grocers in the area (Block and Goldstein 1998). In Boston's Chinatown, the Asian Community Development Corporation is networking restaurants and food businesses for composting. The proposed composting program also could collect food residuals from elementary and high schools in the Green Triangle area. The Reeds Spring School District in Missouri is considering composting options to manage preconsumer food residuals and plate scrapings generated by only 2,300 students and staff (Ling 1999) – approximately one-tenth the number of students in a two-mile radius of the Green Triangle.

A composting facility broadens opportunities for involvement not only by facilities but also by area residents. An expanded collection effort could accept yard waste from the surrounding neighborhoods. Looking further, a food residual composting collection program could be initiated with area neighborhoods. Such efforts, along with the involvement of area schools, would advance one of the primary goals of the Green Triangle coalition: to promote environmental awareness and education.

Location of Anchor Facility

An opportunity for the development of this proposed anchor facility presents itself in the 175 acre area called the Boston State Hospital Site. The Audubon development plan covers only 65 acres of the site, leaving over 100 acres for further development. The Audubon Society recognizes compatibility of the area with other uses, stating, "We expect [our] development to be fully compatible with other site uses. Low-density development in abutting areas would be most compatible with [our] project in order to contribute to the buffer between our program activities and the noise and visual congestion of other development uses (Massachusetts Audubon Society 1995)."

Several proposals have been offered to develop the area, the latest suggestion being the construction of a supermarket. There has been opposition to the supermarket proposal from both the Mayor of Boston and organizations involved in the rejuvenation efforts of the Green Triangle area. They have stated a strong interest in developing the site within the context of the Green Triangle Coalition's common goal of enhancing the area's conservation, recreation, entertainment, and educational benefits.

A composting facility is consistent with the Green Triangle Coalition's goals for the area. The anchor facility would enhance materials exchanges among participants in the EIP, helping to conserve the area's natural resources. The project would offer additional employment for the local community. As the operations of the facility broaden to include material inputs from the surrounding community, there would be an increased sense of community involvement, and a sense of ownership in the success of the Green Triangle area. The increased involvement of the community would serve to educate the community on the interaction of industrial and natural systems.

As the operations of the composting facility broaden to include material inputs from the surrounding community, there would be an increased sense of community involvement, and a sense of ownership in the success of the Green Triangle area.

The anchor composting facility would greatly benefit from the centralized location of the Boston State Hospital site. By maintaining the site within the Green Triangle, transportation costs to and from residual generators would be minimized, making smaller collections on short notice less costly. The site's proximity to Green Triangle organizations provides ready access to a range of professionals who can lend expertise and help manage activities. The 100 acre site also would allow growth of the anchor facility as it expands its scale of operations.

The anchor facility would create even further opportunities for materials exchange by drawing in more tenant facilities. The following section discusses a number of possible tenants that could benefit from the materials exchanges offered by the plan. These suggested facilities are well suited to expanding the EIP and advancing the goals of the Green Triangle Coalition.

Centralized Landscaping Equipment Pool

A landscaping equipment facility could be located adjacent to the composting facility, pooling the equipment needs of the composting facility and Green Triangle organizations. A well-managed and coordinated equipment pool shared among members could help reduce some of the redundancy in the types of landscaping equipment currently purchased by the organizations. Revenue generated from the equipment facility could go toward more costly equipment, such as a "tub grinder" for chipping wood, which individual organizations cannot afford to purchase.

A major hurdle in pooling equipment resources in the past has been concern over joint ownership, with the inherent problems of upkeep of equipment and the coordination of equipment use. The proposed facility would be responsible for the maintenance of the equipment, and could possibly even employ a staff of landscapers, as a need for such a service has been identified. General landscaping maintenance is not, and should not be, a core competency of the Franklin Park Zoo and other Green Triangle organizations. Centralized landscaping operations would provide efficiencies in cost, training, and specialization, reducing overhead of customer organizations through outsourcing.

An equipment pool would provide a more cost-effective and centralized mechanism for handling spent fuel and other equipment fluids in an environmentally responsible manner. The increased scale of operations and equipment maintenance would make processes such as recycling motor oils more standardized, decreasing the probability of smaller discharges throughout the area.

A well-managed and coordinated equipment pool shared among members could help reduce some of the redundancy in the types of landscaping equipment currently purchased by the organizations…[it]would provide a more cost-effective and centralized mechanism for handling spent fuel and other equipment fluids in an environmentally responsible manner.

Nursery and Garden Center

A nursery and garden center located adjacent to the anchor facility could use composting products as input for its own production. Any production from the composting facility in excess of Green Triangle customer needs could be provided to the nursery for on-site use and for retail sale through the garden center. The nursery and garden center also could coordinate purchases with the Arboretum, Zoo, and other organizations to reduce costs through bulk ordering. Material residues, such as the Arboretum's plastic pots, could be reused by the nursery. Green Triangle organizations involved in the composting program could receive credits that go toward the purchase of nursery and garden center products.

The combined facility would further the Green Triangle Coalition's goals of education, recreation, and economic development. Visitors to the Audubon's sanctuary, the Arnold Arboretum, and Franklin Park are likely to have a strong interest in nature, and horticulture more specifically. A nursery and garden center would be a means of taking advantage of this customer niche to generate revenue. Visitors spending a day among trees, flowers, and wildlife may be inspired to develop their own green thumbs. In addition, the nursery and garden center could highlight the environmental benefits of ongoing material exchanges for marketing and educational purposes. Signs could be posted in the garden center identifying local products and explaining the production process. Unique fertilizer products such as "ZooDoo"[2] could be sold through the garden center.

Locating these tenants as extensions of the anchor facility on the Boston State Hospital site creates further opportunities for energy and material exchanges among the co-located facilities. For example, the composting facility could capture heat created from the biological processes involved in composting and funnel this energy to the adjacent nursery and garden center to assist in heating. The garden center could lease landscaping equipment for transporting inputs and moving inventories.

[2] For more information on ZooDoo products, see www.zoodoo.com.

Farmers Market / Craft Fair

A weekly or biweekly farmers' market and crafts fair could take advantage of existing material flows while furthering the recreational and economic development goals of the area. Locally grown produce, especially from the Boston State Hospital Community Gardens, could be sold to visitors, local residents, and restaurants/eateries. The market and craft fair would draw visitors and local residents to the Green Triangle area, helping to enhance the image of a safe, friendly community.

Restaurants

Green Triangle development plans have identified a need for local eateries for visitors. The establishment of restaurants and concessions would enhance value for the area and could become an integral part of material exchanges. These facilities could purchase food from the proposed farmers' market, or directly from community gardens. And as mentioned previously, restaurant food residuals could be material inputs for the composting facility.

Challenges to Implementing Anchor-Tenant Proposal

Primary challenges to developing and operating the proposed anchor-tenant model are ownership issues and the need for information systems. A number of ownership options are feasible for the composting facility and any co-located facilities. It could be operated independently of current Green Triangle Coalition members, purchasing organic residual inputs from surrounding organizations, and leasing landscaping equipment or providing landscaping services. Alternatively, the facility could be managed as a cooperative, with members receiving credits for contributed inputs going toward the purchase of products and equipment services.

An essential component of this proposal would be the establishment of an information and resource management system. For example, the coordination of landscaping equipment lending among participating facilities would need to be managed carefully. Material inputs for the composting facility would need to be tracked to manage fluctuations in supply caused by seasonal variance. Overall operations would require effective management of inventories, supply and demand forecasting, and the establishment of an accounting system to handle cost allocation among co-located facilities.

Information system resources that would be helpful to the development of this proposal would be an interactive database and/or internal web site maintained by the managers of the anchor facility. The status of operations could be updated on the web site, facilitating communication among Green Triangle members. Material and equipment orders, as well as anticipated supplies and demands, also could be coordinated through the web site. The site would provide easy access to information on shared materials, facilitating the planning process for current and future tenants. The Green Triangle Coalition also should work with Industrial Economics, Inc., located in Cambridge, Massachusetts, to share GIS data layers on Green Triangle area businesses that would be helpful in analyzing the growth potential of the proposed facility.

Information system resources that would be helpful to the development of this proposal would be an interactive database and/or internal web site maintained by the managers of the anchor facility.

At this time, we feel that the Lena Park Community Development Corporation is in the best position to manage the proposed facility. They have many of the necessary technologies and business skills, as well as a strong interest in economic development and employment in the area. As a Green Triangle Coalition member, they would help insure that the development goals of the proposed anchor-tenant model complement the overall goals of the area.

Long-Term

In order to increase the connectedness among the EIP facilities, we propose the following, discussed in detail below:

- Use methane from organic decomposition in fuel cells to power trucks and buses travelling between the facilities.
- Convert underground conduits currently used for telephone lines, TV cable, and natural gas into conveyance systems for EIP residues.
- Create an on-line marketplace for buying and selling residues.
- Establish a contiguous greenspace that makes the EIP a single geographic unit that allows easy, pollution-free movement (namely, walking, biking, or roller-blading) and a greater sense of unity between the member institutions.

By adaptively reusing the existing infrastructure, and in some cases creating entirely new infrastructure, we hope to improve the efficiency of materials exchanges and introduce new residues to the system.

"Landfill gas" and Fuel Cells

Fuel cells are electro-chemical machines that convert the chemical energy of hydrogen-containing fuels into electricity. From an environmental standpoint, fuel cells are attractive because they produce no emissions and can use a range of source fuels. One such fuel is methane, which, in combination with carbon dioxide, is known as "landfill gas." The anaerobic decomposition of organic matter, a major constituent in municipal dumps, produces landfill gas. The Green Triangle's proposed composting center would act much like a landfill in this respect. In fact, because the "trash" at the composting center would be entirely organic, landfill gas production would exceed that from a typical municipal dump. According to the U.S. Environmental Protection Agency's Landfill Methane Outreach Program, between 100 and 400 cubic feet of methane is produced per ton of trash (EPA 1999).

The landfill gas could be collected and transported via the Green Triangle Residue Conveyance System (RCS, see below) to the Gas Processing Center (GPC) where the methane, carbon dioxide, and other species will be separated.[3] The Arnold Arboretum's Dana Greenhouses would receive the carbon dioxide by the RCS, while the methane would undergo an additional chemical reaction to produce elemental hydrogen – the target species for the fuel cell – and carbon dioxide. Again, the carbon dioxide would go to the Arboretum, but the hydrogen would be sent by RCS to a fuel cell "refilling station." The long term vision for the Green Triangle includes fuel cell-powered trucks transporting materials between the member institutions. Also, as the Green Triangle becomes a major tourist destination, fuel cell-powered buses could transport visitors between the Arboretum, Zoo, Audubon Society, the metro stop, and other area locations. Both the trucks and the buses would "refill" at this station, which would be centrally located.

In addition to creating new links within the Green Triangle EIP, the reuse of landfill gas has two important environmental benefits. First, both carbon dioxide and methane are greenhouse gases. By creating new sinks, the EIP would keep these gases from entering the atmosphere. Second, as anyone who passes a landfill knows, a pungent smell envelopes these facilities. Because methane is the source of some of this odor, the Green Triangle EIP would have a secondary, aesthetic, environmental benefit.

Residue Conveyance System

Miles of pipes, carrying telephone wire, TV cable, and natural gas, run under the Green Triangle area. The current push in technology toward wireless and satellite communication systems means that these wires and cables – and their conduits – may become obsolete. A zero emission Residue Conveyance System (RCS) is proposed that would use the obsolete underground pipes to move materials among Green Triangle facilities. Food waste, manure, and woodchips would be the primary residues carried through the RCS. A certain amount of retrofitting of pipes would be necessary. The existing telephone and cable lines

[3] The typical chemical breakdown of landfil gas is 50% methane, 39% carbon dioxide and 11% other (EPA 1999).

would need to be removed, and the pipes sealed with an inner sleeve or other methods to create a vacuum. Pumps would be installed to quickly move the material through the system.

Due to the long depletion time of natural gas, the pipes for this fuel will likely be in use for many decades. However, multiple use of the pipes is possible.[4] The Gas Processing Center (GPC), introduced in the above section, would regulate the flow of natural gas, hydrogen, methane, and carbon dioxide through these pipes. It is expected that natural gas would predominate the flow and that the other gases would be conveyed at discrete times during the day. A limitation on the use of natural gas lines is that, unlike phone lines, they do not run everywhere, but are pervasive enough to allow for a comprehensive and easily expanded RCS.

Virtual EIP Marketplace

Transaction costs are an obstacle to increasing the efficiency and number of residue trades. First, a Potential EIP Participant (PEP) must search for facilities that produce the desired residues or, if the PEP has residues to sell, find a potential buyer. Second, the PEP must determine whether the quantities produced (desired) are sufficiently high to induce a transfer. Third, the parties must negotiate a price.

All of these steps and others can be eliminated through a virtual EIP marketplace. A NASDAQ-type system is envisioned, with all existing and potential Green Triangle participants on-line and able to determine the quantities and prices of available residues. An additional feature of the marketplace might be a "trigger" mechanism that releases stocks of purchased residues into the RCS at times specified in the transaction.

Contiguous Greenspace

Most of the Green Triangle facilities are directly adjacent to one another, but a key member, the Arboretum, and the metro stop are both located on the opposite side of Washington Street (see map). A swath of greenspace running from the Forest Hills Cemetery to the Arboretum would create several advantages. First, if all the natural elements of a park, including trees, shrubs and grass, are added to this connector greenspace, then the flows of organic materials through the Green Triangle will be increased. Second, the creation of new pathways means an opportunity for the reuse of construction and demolition material, such as crushed bricks, or the application of woodchips to create pathways. Third, if all the facilities are connected in a way that is attractive to pedestrians, bicyclists and rollerbladers, then fewer cars will be used to move between the Green Triangle destinations. And lastly, the contiguous greenspace will have the less tangible, but no less important, benefit of reinforcing the connectedness between facilities. By creating these physical links, EIP institutions may be less likely to view themselves as self-contained individuals and more as members of a self-reinforcing group.

CONCLUSION

The Green Triangle area represents a tremendous opportunity for the development of an eco-industrial park. The park, as proposed above, will enhance profitability of existing enterprises by reducing input needs and adding value to residual streams. The enterprises envisioned will dovetail with existing plans for community revitalization by creating jobs, and by fostering a sense of connectedness to the Green Triangle area. While existing efforts seek to instill the notion that facilities in the Green Triangle are related, the eco-industrial park plan adds substance to that notion. The park will demonstrate how entities can use each other to fulfill their own needs and to capture synergies that fulfill the needs of others outside of the individual "firms." The eco-industrial park, under effective management, could become an entity in and of itself, providing an additional reason for people to visit the area.

On a more general note, our experience evaluating the potential for an eco-industrial park in an area targeted for revitalization has illustrated substantial value in combining efforts to increase efficiency and exchange materials among firms with redevelopment initiatives. The field of industrial ecology stands to benefit from the living laboratories that such regions provide, while redevelopment efforts can gain from a tool that graphically illustrates the interconnectedness among people, places, and organizations.

REFERENCES

Arnold Arboretum, *Director's Report 1996–1997.*

A.T. Kearney, Inc. December, 1996. Business and Operations Plan, prepared for the Franklin Zoo.

Block, D. and N. Goldstein. February, 1998. Plans Abound for In-vessel Composting. *Biocycle.*

Boston Consulting Group. 1998a. Presentation materials.

Boston Consulting Group. 1998b. Budget forecasts.

Environmental Protection Agency (EPA). 1999. Landfill Methane Outreach Program website. http://www.epa.gov/lmop/

Ling, Doug. 1999. Asian Community Development Corporation. Personal communication.

Massachusetts Audubon Society. May, 1995. *Proposal to the Massachusetts Division of Capital Planning and Operations for the Redevelopment of the Boston State Hospital Site.*

Part III: Integrated Bio-Systems

Integrated Bio-Systems: Mushrooming Possibilities 2000

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ABSTRACT
Our paper analyzes the strengths and weaknesses of a subfield of industrial ecology called integrated bio-systems (IBS). Consistent with the principles of industrial ecology, the goal of an IBS is to reduce pollution by transforming linear material flows into closed, cyclical processes that produce value-added product. The presence of large, concentrated quantities of compost, generated as a residue during the mushroom growing process, creates an opportunity to develop innovative on-farm uses for this material. We consider two potential options: (1) a mushroom farm/mycorrhizae IBS; and (2) a mushroom/biogas recovery IBS.

INTRODUCTION

Agriculture – the science, art, and business of soil cultivation, crop production, and animal husbandry – has evolved over time to meet the demands of a changing world. In general, population growth and rising demand for food has led to an intensification of agriculture characterized by increased use of capital and other inputs. This trend has increased the potential for "spillovers," or material losses, and environmental degradation.

Cyclical versus Linear Systems

Traditional agricultural systems were cyclical in nature. For example, early agrarian societies would grow crops, raise livestock, and spread the livestock manure on fields to enhance crop production. Integration of these processes created a relatively closed, self-sustaining system based on principles of conservation of resources and limited wastes. The industrialization or "modernization" of agriculture over the last century, however, has been the main factor in transforming agriculture from a cyclical process to a linear process, through which large quantities of raw materials are consumed and large amounts of waste are emitted. Figure 1 illustrates this transformation (Allenby and Graedel 1995).

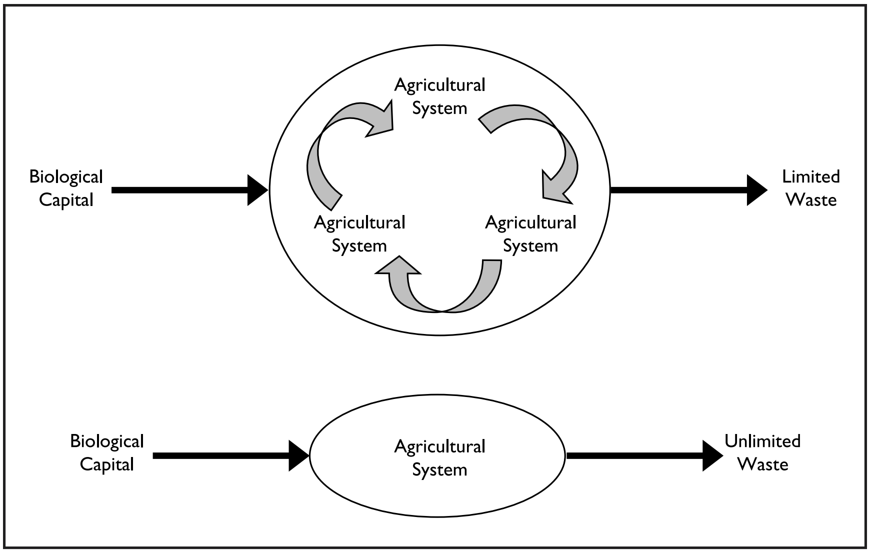

Figure 1 Cyclical versus Linear Systems

Agriculture as a Cause of Environmental Pollution

This fundamental change in agricultural practices has resulted in agriculture becoming a leading cause of some of today's most pressing environmental problems. Some of the common environmental problems associated with agriculture include: soil erosion, salinization, depletion of nutrients, methane emission, wastewater runoff, leaching of pesticides, and disposal of large quantities of solid waste (e.g., manure, crop residues).

It is important to remember, however, that the practice of agriculture is not an inherently polluting activity. It is only when such practices are poorly designed – when they concentrate and discharge large quantities of potentially harmful residues – that they undermine natural systems.

INTEGRATED BIO-SYSTEMS

Return to an Integrated System

Today, many efforts to move toward more sustainable agricultural practices are based on the theory of integrated bio-systems (IBS). According to the Zero Emissions Research and Initiatives (ZERI) Foundation, an IBS is a system that:

> ...[I]ntegrates at least two [biological] sub-systems so that the wastes generated by the first system are used by the next biological sub-system to produce a value-added product(s). The general aim of an IBS is to turn a material flow with losses that contribute to pollution into a closed and integrated one where nutrients are recovered by plants and animals.

The cyclical structure of these dynamic systems is not revolutionary. In fact, the fundamental composition of the IBS represents a return to the highly integrated agricultural systems that preceded industrialization.

It is important to remember, however, that the practice of agriculture is not an inherently polluting activity. It is only when such practices are poorly designed – when they concentrate and discharge large quantities of potentially harmful residues – that they undermine natural systems.

The IBS concept closely resembles that of industrial symbiosis, an area of industrial ecology that "engages traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and by-products" (Chertow 1999). As is true of industrial symbiosis, the key factors in IBS are the interdependence or collaboration between component systems, and the synergistic possibilities offered by geographic proximity. Unlike industrial symbiosis, however, IBS is focused on biological, not industrial systems (UNU/IAS 2000).

A Model IBS

The Montfort Boys' Town located in Suva, Fiji, is heralded as a model IBS. The Montfort IBS was designed to alleviate off-shore dumping of large quantities of brewery waste, which was hazardous to nearby coral reefs. Montfort integrates four biological subsystems: mushroom farming, pig raising, fish farming, and vegetable growing. The primary input to the agricultural system is spent grain from the beer breweries[1] (Klee 1999). A diagram of the Montfort IBS is shown in Figure 2. The main goal of an IBS is to minimize material losses from the system, and hence, to reduce the potential for environmental impact.

[1] Bagasse, a fibrous waste from sugar cane processing, can also be used as an alternative input.

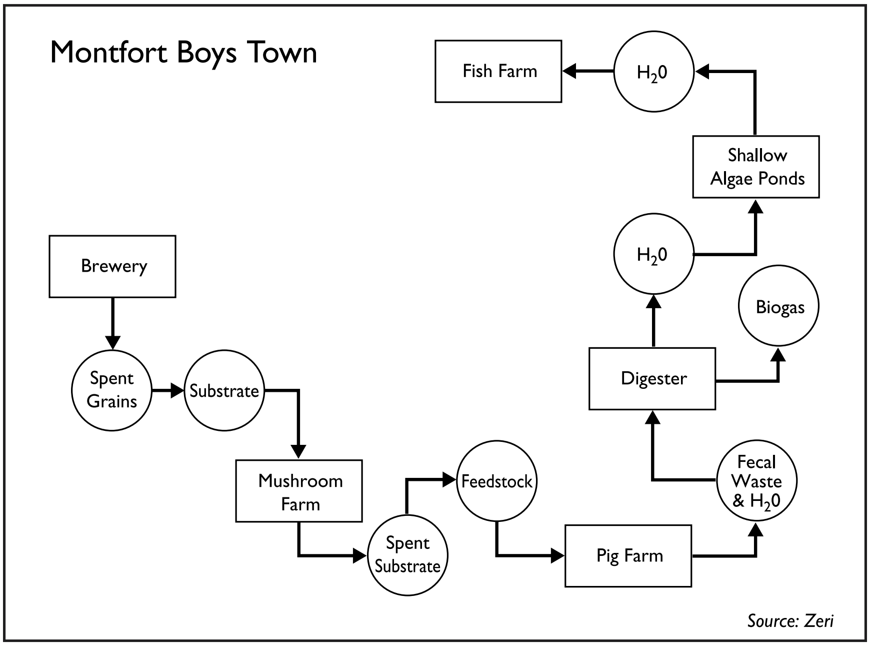

Figure 2 A Model IBS (Montfort Boys' Town, Suva, Fiji)

Translating IBS in an Industrial Context

There is little doubt that integrated bio-systems are replicable. In fact, as long as a system features a set of unambiguous inputs and outputs in a simple, well-defined, and controlled environment, it is reasonable to assume that it could be installed just about anywhere. The Montfort Boys' Town model, for example, demonstrates that a modestly diverse array of sub-systems can be elegantly combined to match material flows between them. This particular arrangement of interrelated component systems reflects an explicit industrial ecology objective, and as such does not exhibit an architecture shaped by truly diverse, variable, or complex external forces. Any effort to recreate an IBS in a real-world industrial context would require the modification of IBS fundamentals to address and incorporate a far more dynamic and uncontrollable set of sub-systems and variables.

The major challenges involved in the adaptation of the IBS model to modern industry derive from the structure and mechanics of the marketplace. Whereas the Fiji model has operated within the confines of a micro-scale experimental program, it has not been exposed directly to the conditions and nuances of a large and highly evolved market. If an integrated bio-system is to function effectively at the corporate level in a sophisticated economy, its designers must be attentive to the following critical issues: 1) the maturity of component operations; 2) operational scale and input/output parity; 3) financial and fiduciary obligations vs. ecological objectives; 4) myriad competitive forces; 5) the complexity and diversity of material flows, and 6) co-location of component systems.

Maturity of the Component Operations: Corporate Inertia

The Fiji model incorporates sub-systems featuring very short operating histories – most did not even exist prior to development of this micro-IBS. Of course, this is not likely to be true of the component systems of an IBS in a larger and more sophisticated industrial context. Inevitably, the implementation of a large-scale industrial IBS will require the inclusion of existing, often highly mature, businesses. Since these businesses will almost certainly have established policies, strategies, and methodologies – the aggregate of which we have dubbed "corporate inertia" – integrating them into an IBS poses far greater challenges than does the integration of nascent entities. Ultimately, it is the corporate inertia of a potential component entity that will determine its suitability for inclusion in an IBS, even if the entity's underlying activities lend themselves, in theory, to inclusion.

Operational Scale and Input/Output Parity

The IBS at Montfort Boys' Town was developed to consume and metabolize the waste stream from brewing and sugar processing operations. Because the volume of the material outputs was measurable and consistent, the system designers were able to build a mushroom farming sub-system of the appropriate scale to match those volumes and to accept the flows as inputs. In a larger industrial context, characterized by operations of varying scales, input/output disparity will be commonplace. For instance, as we consider the feasibility of converting spent grain output from Connecticut brewers into a high-nutrient input for mushroom cultivation at Franklin Farms, one of the nation's largest mushroom farms located in Connecticut, it becomes abundantly clear that a material flow disparity exists. The volume of waste material emitted from Connecticut brewery operations (more than forty in all) is an order of magnitude greater than the input demand and capacity of even a large commercial mushroom operation like Franklin Farms. We believe that the input/output disparity between these industries is even wider on a larger regional and national basis.

Financial and Fiduciary Obligations vs. Ecological Objectives

The feasibility of any economically viable IBS will largely depend on the willingness and ability of the business managers to strike a balance between financial and ecological goals. While the Fiji IBS features industrial and agricultural processes that could, in theory, achieve profitability in addition to the environmental sustainability that the system has demonstrated, the development of the system was not contingent on the realization of explicit financial returns. The economic realities of modern businesses and markets, however, would be heavily involved in any decision to implement an IBS in a real-world industrial context. While we are confident that integrated bio-systems offer tremendous opportunities for both improved ecological and financial performance, we feel that it is very important that IBS feasibility studies address the economic motivations behind corporate decision making and behavior.

Myriad Competitive Forces

At the risk of redundancy, we would like to stress again how much more complex, rigorous, and uncertain the modern industrial context is compared to the environment in which the Fiji IBS was developed. It is instructive to consider that the five major forces outlined in Michael Porter's seminal tome on competitive strategy, *Competitive Strategy: Techniques for Analyzing Industries & Competitors,* have as much influence on the utility and efficacy of a corporate IBS as they do on any other aspect of a company's well-being. Competition, buyer power, supplier power, substitution, and barriers to entry are not conditions that discriminate in the manner or degree of their influence, and as such they are extremely relevant to any company's decision to participate in an IBS.

Complexity and Diversity of Material Flows

The types of materials used in large-scale mushroom cultivation, as well the distinct channels through which inputs and outputs flow, are numerous and varied. As we will discuss later in the paper, mushroom farmers have a fair amount of flexibility in choosing their sources and types of inputs. With so many options available to them, these farmers have the freedom to incorporate non-operating factors into their sourcing decisions, thus improving the likelihood that the farm could be integrated into an IBS. Nonetheless, the complexity and diversity of the material flows can also hinder attempts to combine and fully account for all of the component systems and their related material fluxes.

Co-Location of Component Systems

One idea that the diagram of the Fiji system is intended to convey (see Figure 2) is that the efficiency of the overall system depends in large part on the relative location of its component systems. It stands to reason that the integrative character of the IBS is more readily achievable when the sub-systems are located within close proximity to one another – a feature typically referred to as "co-location". Due primarily to the small scale and relative nascence of the Fiji model, there appeared to be few obstacles to co-locating the six sub-systems mentioned earlier. In a larger industrial context, characterized by mature and often disaggregated industries, co-location almost certainly constitutes a much greater endeavor than the one undertaken in Fiji.

MUSHROOMS: A KINGDOM UNTO THEMSELVES

Overview of Mushrooms

The mushroom is a fascinating form of life. Mushrooms are so distinctive that they are classified in their own "kingdom," a mostly microscopic community that performs invaluable roles in all terrestrial ecosystems (Miller 1972). Mushrooms are decomposers, releasing stored nutrients for use by host systems. In their association with living plants, mushrooms also facilitate the exchange of nutrients from organism to organism, and from one medium to another. Given mushrooms' extensive utility, it is helpful to think about how they are used in agriculture today, and to consider in what new ways the mushroom "kingdom" might be utilized in an industrial IBS context.

It has been estimated that there are 1.5 million species of fungi, of which only 5% (or approximately 69,000 species) have been identified. Out of the described species of fungi, there are about 10,000 species of fleshy macrofungi, the kind that form the fruiting bodies that enable us to readily identify them as mushrooms. While everyone is warned at some point or another not to eat mushrooms found growing wild, nearly half of all macrofungi are, indeed, edible. Further, of these 5,000 edible species, only a dozen or so are commonly cultivated. Finally, of this small, special group of mushrooms, one species predominates in agriculture: the common white mushroom of the genus *Agaricus*. The white mushroom comprises more than 99% by weight of all industrial mushroom cultivation (Miller 1972).

Mushroom Growing Trends and Economic Factors

Mushroom production is expanding worldwide. Last year in the United States (1999), *Agaricus* mushrooms totaled 848 million pounds, representing an increase of 5% from 1998, and 9% above 1997 levels. Pennsylvania accounted for half of the total volume of mushroom sales and California ranked second in production, with 16% of the U.S. total. The value of this *Agaricus* crop was estimated at $829 million, compared with $774 million for 1998. Brown mushrooms, such as the Portabello and Crimini varieties, are in fact another member of the *Agaricus* genus. The production of brown mushrooms has doubled in the past two years, accounting for roughly 5% of the 1999 *Agaricus* harvest. Brown mushrooms are nearly 10% more valuable than their white cousins (USDA 1999).

Despite the recent increase in mushroom production, the number of mushroom farms in the United States has been declining at an annual rate of 5% for the last 20 years. In 1999, only 150 farms grew *Agaricus* varieties. Nonetheless, 11 of those 150 farms realized sales of more than 20 million pounds in the 1999 season. Growers with sales exceeding 10 million pounds accounted for 60% of U.S. *Agaricus* production. Thirty-nine farms produced less than one million pounds each (USDA 1999).

As one might deduce from these statistics, the sharp decrease in the number of operations has been more than offset by significant increases in both the production footprint and yield. In 1999, the total growing area reached 35.2 million square feet in the United States, an increase of 2% over the previous year. In the same year, farm yields averaged 5.65 pounds per square foot, matching the second highest annual figure on record (the highest average yield was 5.69 pounds per square foot during the 1996-97 season) (USDA 1999).

Shiitake and Oyster mushrooms, referred to as "specialty mushrooms," are the two other major mushroom species grown in this country and constitute about 1% of the total mushroom harvest. These mushrooms have different growth requirements than *Agaricus* and bring a substantially higher price, averaging \$2.97/lb. compared to \$0.97/lb. for *Agaricus* varieties. In 1999, thirteen million pounds of these specialty mushrooms were grown. Their production has doubled in only the last two years (USDA 1999).

Mushrooms and Industrial Ecology

From an industrial ecology perspective, several things are important about modern mushroom farming trends. First, farm consolidation means that bigger and more productive operations are generating more waste on a per-farm basis, causing these waste streams to become highly concentrated regionally. Second, many of the gains in productivity have accrued from methods that impose greater throughput and stresses on the growing facilities and their local environment. Compounding this impact is the fact that mushrooms are increasingly cropped on shorter rotations. It is more efficient for the mushroom farmer to increase throughput than to wait for a second or third flush of mushrooms from a batch of compost. As a result, more nutrients are left in the waste stream.

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THE MUSHROOM GROWING PROCESS

We decided to examine mushroom cultivation through the lens of industrial ecology in order to gain an understanding of how this agricultural activity might be integrated into a successful IBS. We identified the materials flowing into typical mushroom operations, pinpointed when and where in the process they are employed, and outlined the impacts of the various emissions. The mushroom growing process consists of seven general stages, each of which requires its own distinct recipe of inputs and, subsequently, releases a unique set of outputs.

In the following section, we describe in some depth the individual stages of mushroom cultivation, and begin to frame the factors that will either limit or enhance opportunities for process innovation in the context of the development of an integrated bio-system. Figure 3 provides a simplified diagram of the mushroom growing process. As noted, a full mushroom growing cycle is approximately 10 to 15 weeks from delivery of compost to harvest of mushrooms.

Authors' note: the following descriptions of the mushroom growing process are taken from Wuest et al., *"Six Steps to Mushroom Farming." Some of the information has been shortened; however, the format and text are the work of these authors.*

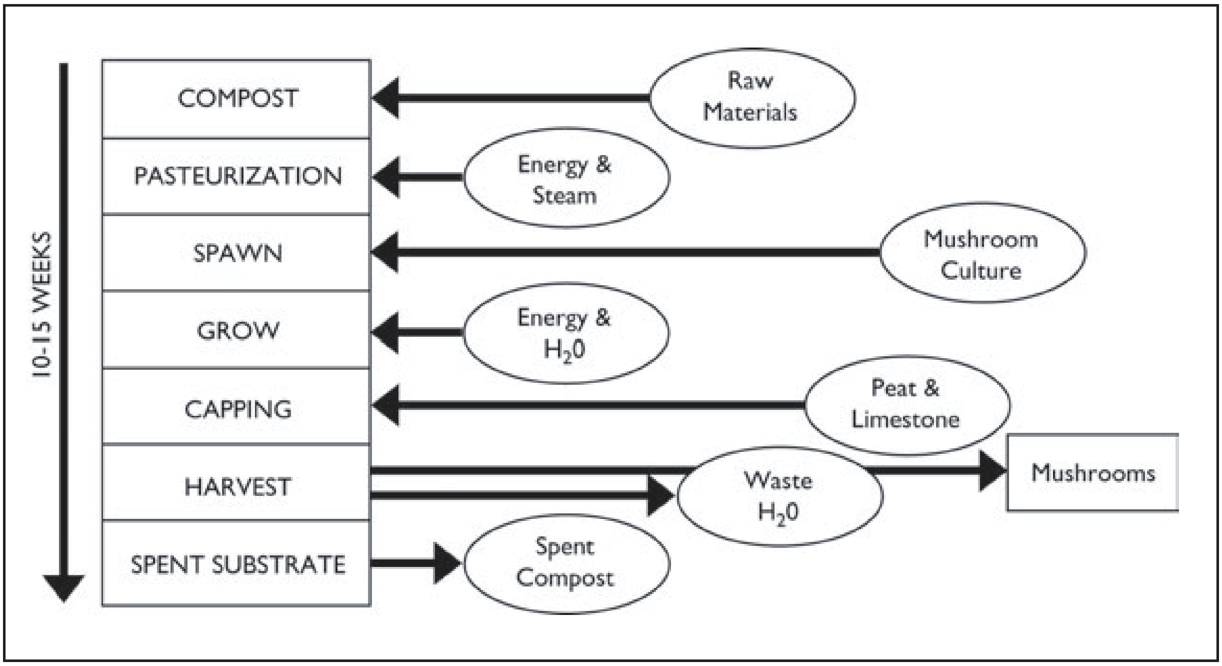

Figure 3 The Mushroom Growing Process

Stage One: Mixing Compost

The mushroom growing process starts with the formulation of a species-specific "substrate," a mixture comprised of composted organic and mineral ingredients which is intended to support the growth of the given type of mushroom. While farmers have considerable latitude in the approach they take to formulating compost, it is the most critical aspect of mushroom cultivation. Ironically, there is some evidence showing that this is the stage of the process most prone to farmer error.[2] A typical compost mixture for a modern farm is as follows:

- 50 parts straw-bedded horse manure
- 1 part dried poultry manure
- 1 part dried brewer's grain
- 1 part gypsum

[2] According to Bruce Wilkinson at Franklin Farms in Franklin, Connecticut, however, roughly 90% of farms formulate optimal compost for proper cultivation.

The quantity of materials used in a particular farm is proportional to the size of the farm. On average, farms in the U.S. produce two pounds of mushrooms per square foot of bedding each month. The ratio of compost to mushroom production is generally 2:1. Therefore, a large farm capable of producing 20 million pounds of mushrooms per year (there are 11 such farms in the U.S.) would need to utilize on the order of 1,500 tons of compost per month.

The set of potential compost ingredients is extremely broad, and varies widely according to the location of the farm, the nature of surrounding industries, and the types of mushrooms grown. Given the fundamental compost requirements and the spectrum of alternative ingredients, it is quite apparent that much of the compost material can be obtained from the waste streams of other processes.

Table 1 lists common compost ingredients, the rationale for their inclusion, and their relevance to three important environmental issues. The three environmental issues noted include: leaching potential during composting (L), energy required in production (E), and recycled vs. virgin origin (R). In order to facilitate development of a Life Cycle Assessment (LCA), we ranked each of the "rationale" and "environmental issue" elements according to its overall environmental significance.

Our ranking system revealed that the ingredients that have a high potential to leach also tend to be virgin materials, and that the processing of these materials requires a great deal of energy. One exception to this trend is that chicken manure (a waste input) exhibits a high concentration of nitrogen, which is very susceptible to leaching during the composting process.

It is also interesting to note that modern mushroom operations recycle and reuse a vast quantity of nutrients that are by-products of other industries, such as horse stables and chicken farms. The great scale and rate of this material flux amplifies the relevance of mushroom farming as a potential integral component of integrated bio-systems. While it is apparent that examples of material exchanges abound in the mushroom industry, a detailed LCA of myriad exchanges was beyond the scope of this exercise. Nonetheless, we feel that it is particularly important to consider how the issue of scale effects the material inflows to a farm. For instance, it would be useful to know whether large farms use more or less raw materials than small operations. Do operations require a certain percentage of virgin material to ensure consistent quality and productivity? We believe that the trend in farm consolidation is a clear indication that economies of scale have a significant impact on the cost of production. Whether these economies of scale translate into benefits for the environment is unclear from our study of the process.

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Stage Two: Managing the Pile

Once the compost ingredients are mixed, they start to decompose, a process through which the embedded nutrients are converted into forms that are useful

Table 1 Mushroom Substrate Ingredients

INGREDIENT	RATIONALE*				TYPICAL SOURCE	ENV. ISSUES		
Element [Rank]	N[1]	C[2]	B[3]	O[4]	Element [Rank]	L[5]	E[6]	R[7]
Standard Ingredients								
Corncobs (whole, ground, crushed, pelletized)	X	X	X		Corn farm, corn sheller		?	?
Hay	X	X	X		Hay farm		X	
Horse manure – straw bedded	X	X	X		Horse farm			
Poultry litter/manure	X				Poultry farm	X		
Straw		X	X		Grain farm			
Possible Other Ingredients								
Adco	X				Fertilizer plant	X	X	
Ammonium nitrate	X				Fertilizer plant	X	X	X
Animal fat	X				Meat processor	X		
Brewers grains (wet or dry)	X				Brewery	X		
Corn fodder		X	X		Corn farm		X	X
Dried blood	X				Poultry or meat processor	X		
Feathers or feather meal	X				Poultry processor			
Fish solubles	X				Fish processor	X		
Grape pumice		X			Grape processor			
Ground wallboard				X	Construction industry			
Gypsum				X	Gypsum rock			
Gypsum, synthetic				X	Soil conditioner supplier			
Hardwood bark		X	X		Sawmill			
Hardwood tree leaves		X			Municipal leaf collection			
Licorice root	X					?		
Lime				X	Soil conditioner supplier			
Livestock manures	X				Livestock farm			
Mushroom stumps and culls					Mushroom farm			
Paunch		X			Meat processor	X		
Peat moss					Peat bog		X	X
Potash, potassium					Fertilizer plant	X	X	X
Potato waste		X			Food processor	?		
Seed-hulls		X			Seed processor			?
Seed-meal	X				Seed processor	X		?
Seed-oil	X	X			Seed processor			?
Shredded newspaper		X			Newspaper recycler			
Sugar cane (bagasse)		X	X		Sugar processor	?		
Sugar cane (pulp)		X			Sugar processor	?		
Urea	X				Fertilizer plant	X	X	X

KEY TO TABLE

*Rationale:
1= Nitrogen
2= Carbon
3= Bulk
4= Flocculent or pH control

Environmental Issue:
5= Leachability
6= High Energy Use
7= Virgin Material

to mushrooms. The goal of composting is to produce a food source suited to the growth of a specific mushroom, to the exclusion of competing fungi and bacteria. The proper proportions and amounts of water, oxygen, nitrogen, and carbohydrates must be present throughout the process to achieve optimal growing medium.

The preparation of mushroom compost occurs in two steps, referred to as Phase I and Phase II composting. Phase I compost preparation usually occurs outdoors, although an enclosed building or a roofed structure may also be used. The compost is managed in a compost turning yard, also referred to as a wharf yard, which consists of a flat slab of concrete, asphalt, or a low-permeability earthen material. Compost-turning machines are used to mix and water the ingredients, while bucket loaders move the ingredients on the turning yard.

Phase I composting begins on many mushroom farms with a preliminary or "pre-wet" step, in which large heaps of a hay/straw mixture are soaked with water. The wetting step accelerates the growth and reproduction of microorganisms naturally present in the mixture, which leads to the production of heat. This serves to soften the hay and straw, making it more water absorbent. These heaps may be mixed together to produce a uniform starting compost. The pre-wet stage lasts from between 3-4 days to 12-15 days, depending on a range of operating conditions.

Following the pre-wet stage, the materials are arranged in a long pile over which nitrogen supplements and gypsum are spread. The pile, often referred to as a "rick" by farmers, is thoroughly mixed with a turning machine. Aerobic composting continues after the pile is wetted and formed.

The compost pile must be carefully erected and managed. Most compost piles are roughly five to seven feet wide, five to ten feet high, and as long as necessary or practical. The rick must hold its shape, while remaining loose enough to allow for aerobic conditions throughout. Turning and watering are done at approximately two-day intervals. Turning provides the opportunity to water and mix the ingredients, as well as to relocate the compost from the cooler exterior to the warmer interior, and vice versa. The aeration accomplished by turning is short-lived, so pile construction, structure, and contents are critical in promoting aerobic degradation. The number of turnings and the time between turnings depends on the condition of the starting material and the time necessary for the compost to heat up.

Water addition is critical. Too much water will exclude oxygen by occupying pore spaces, and may lead to an unnecessary loss of nutrients due to leaching, while too little water can limit the growth of bacteria and fungi. As a general rule, most of the water is added when the pile is formed and at the time of first turning. Thereafter, water is added only to adjust the moisture content. On the last turning of Phase I composting, water may be applied generously to carry sufficient water into Phase II. Water, nutritive assets, microbial activity, and temperature are like links in the composting chain. When one factor is limiting, the efficacy of the process may be diminished.

One of the management issues that farms often face is the creation of odor during the composting. These odors, which constitute a significant negative externality, are generated if mixtures are improperly formulated, or if piles are poorly managed. One way that farms are addressing this problem is through the use of aerated silos that force air into the compost mix. These innovative silos employ air jets embedded in the floor to introduce oxygen to the substrate, and feature solid walls to ensure the even distribution of air throughout the structure.

In July 1998, Pennsylvania-based Hy-tech Compost engineered an aerated silo that enables managers to monitor and adjust temperature, airflow, and odor using a centralized computer. Hy-tech reports that, in addition to mitigating odor emissions, this technology can reduce composting runs to as few as 9-12 days, compared to 16-21 days for traditional methods. Systems such as this also increase the likelihood that future composting operations will move indoors, where leaching can be controlled or eliminated entirely.

Stage Three: Compost Pasteurization

Once the compost has reached a proper state of decomposition, the pile is transferred to a separate room, where it sits for 48 hours at 132°F. Raising the air and compost temperature to 140°F initiates the pasteurization process, which lasts two hours. The pile is then gradually cooled over the next five days, or until it reaches a temperature of 85°F. Pasteurization uses far more energy than any other process during the mushroom cultivation.

Pasteurization is conducted to kill any insects, nematodes, competing fungi, or other pests that may be present in the compost. The heating process also reduces ammonia levels by favoring the growth of thermophilic (heat-loving) organisms that consume carbohydrates and nitrogen. High ammonia levels can be lethal to mushroom spawn.

Stage Four: Spawning

Spawning is the mushroom culture equivalent of planting seeds for a field crop. Whereas vegetable crops are planted using fruiting seeds, mushrooms are "planted" using fungal mycelia. Fungal mycelium propagated vegetatively is known as spawn (Latin expandere = to spread out). Making spawn requires laboratory facilities that are not contaminated by the mycelia of other fungi. The spawning process starts with the sterilization of a mixture of cereal grain, water, and chalk. Once bits of mycelia have been added to the sterilized porridge, the mix is incubated to promote mycelia growth.

At the mushroom farm, spawn is thoroughly mixed into the compost using a special machine. After the spawn has been blended with the compost, the compost temperature and the relative humidity in the growing room are managed to optimize mycelia growth. The spawn grows out in all directions from a spawn grain. The time needed for spawn to fully colonize the compost depends on the amount and distribution of the spawn, the compost moisture and temperature, and the nature or quality of the compost. Completing the spawn run usually requires 10 to 21 days.

Stage Five: Casing

Casing is a top-dressing applied to the spawn-run compost, and is necessary for mushrooms to develop from the mycelia that have grown throughout the compost. It can be comprised of clay-loam field soil, a mixture of peat moss with ground limestone, or reclaimed spent mushroom substrate (SMS) and is used not to supply nutrients, but rather to act as both a water reservoir and a rhizomorph habitat. Rhizomorphs, resembling thick strings, form when the very fine mycelia grow together. Casing holds moisture that is required to produce a firm mushroom. Immediately following casing, water must be applied intermittently to raise the moisture level of the bed to a maximum capacity, ensuring that mushroom pins will form.

We discovered that recent innovations in the casing process have already improved the environmental performance of mushroom cultivation. Traditionally, the casing mixture included peat moss – a product produced from a virgin source and trucked long distances. Early research into the growing process showed that peat moss casing improved crop production by about 6% each year. Today, the mushroom industry has found a way to reuse spent mushroom substrate (SMS), thus recycling the industry's most voluminous by-product and eliminating its reliance on peat. Farmers have also found a way to employ SMS to reduce the incidence of a disease called verticillium.

Stage Six: Pinning

Mushroom fruiting bodies – referred to as initials, primordia, or pins – are small outgrowths from the rhizomorphs that form in the casing layer. These fruiting bodies continue to grow larger through a button stage, and ultimately enlarge into mushrooms. Pinning affects both the potential yield and quality of a crop.

Stage Seven: Cropping

Harvestable mushrooms appear 16 to 28 days after casing. Following a successful pinning, blooms of mushrooms called "flushes" or "breaks" make their appearance. Once mature mushrooms are picked, an inhibitor to mushroom development is removed, and the next flush moves toward maturity. This regrowth process is repeated in a 7-10 day cycle, and harvesting can be repeated as long as mushrooms continue to mature.

The length of the harvest is a concern from an industrial ecology perspective, as well as from a business perspective. Most mushroom farmers harvest for 25 to 35 days, but harvest can continue for as long as 150 days, with yields decreasing over that period. Temperature, water management, and ventilation continue to be critical parameters throughout the growing period, but the most critical aspect is the potential buildup of disease pathogens and insect pests that can cause crop failure and lead to increased costs and use of pesticides. These pathogens and insects can be controlled through sanitary conditions, good tool cleaning, and isolation of the crop – or through the use of pesticides. However, a farm that uses shorter harvesting cycles reduces the time for pests to become established and to proliferate in the growing room. Once a crop is finished growing, the area is thoroughly cleaned, a necessary procedure to destroy any pests that might be present in the crop or the growing room. Cleaning and rinsing are a major source of wastewater, as growing areas are often treated with sanitizing agents.

END-OF-LIFE CONSIDERATIONS

The overriding industrial ecology problem facing the mushroom industry is the disposal of spent mushroom substrate (SMS). In this country, mushroom farms have to handle nearly half a million tons of SMS annually. While this material is high in nutrients and has numerous uses, there are few viable options for disposal beyond the mushroom farm. Because the mushroom industry is geographically concentrated, the number and diversity of local uses for farm waste is limited. The seasonality of local agricultural businesses compounds this bottlenecking condition, by severely restricting the scheduling of outflows of SMS.

The overriding industrial ecology problem facing the mushroom industry is the disposal of spent mushroom substrate (SMS).

As a result, SMS often accumulates to unwieldy volumes, creating odor, disease, and nutrient leaching problems. Odors and nutrient runoff have a noticeable, detrimental impact on the local environment. Research has shown that a three-foot pile of SMS leaches 2,500 pounds of nitrates per acre into the soil – 25 times the average nitrate level for a fertilized cornfield. A five-foot pile releases 60 times the nitrates found in a fertilized cornfield's soil. In addition, leachate from SMS can have up to 100 times the organic carbon of pondwater (5,000 and 10,000 milligrams per liter vs. 100 to 200 for a nutrient rich swamp) (PADEP 2000).

We looked at the various means by which mushroom farmers might deal with these pollution problems and broke them down into two different categories: 1) short-term management solutions, and 2) longer-term uses for the SMS and wastewater.

Short-term Management Solutions

In general, mushroom substrate retains much of its original nitrogen and carbon content when it exits the operation and contains significant amounts of potassium, calcium, and magnesium. These five elements are highly leachable and create problems for the reuse and disposal of SMS. The traditional method for handling this problem is to allow the SMS to naturally weather in the field, either through active or passive composting. To prevent the leaching materials from entering the environment, both of these methods must be implemented with diligence and discipline (PADEP 2000).

Passive composting or curing involves creating shallow piles of SMS, and allowing it to decompose naturally into a more stable, humus-like product. This material can then be used as casing in mushroom growing operations or for other agricultural purposes. This system cannot maintain the same high temperature conditions necessary for rapid composting and, therefore, results in slower decomposition.

The advantages of passive composting come from the minimization of labor and machine inputs during the composting process. The disadvantages include longer composting times, increased exposure to runoff problems, and large land area requirements.

Active composting involves mixing the SMS, and forming it into elongated piles or windrows, which are periodically turned or agitated. This process provides faster decomposition due to higher temperatures within the mass of the pile. Turning the pile provides temporary cooling of the hot interior, transfers cool outer material to the pile interior, prevents compaction, and disperses gases and water vapor (PADEP 2000).

Best Management Practices

Many pollution problems associated with composting can be alleviated simply through the adoption of best management practices. For a passive composting operation, such practices would include:

- Maintaining shallow piles less than three feet to discourage anaerobic conditions and odors;
- Preventing stormwater runoff;
- Applying vegetative cover.

The best management practices for active composting include:

- Composting on a concrete or compacted low-permeability surface;
- Collecting waste liquids for reuse in the composting process, or for storage and treatment;
- Managing piles to maintain aerobic conditions;
- Diverting stormwater runoff to controlled areas. (PA DEP 2000)

Potential Reuse of Spent Substrate

Among the most simple and inexpensive uses of SMS and wastewater produced in a mushroom farm is to apply them to agricultural land as a substitute for nitrogen-phosphorous-potassium (NPK) fertilizers, and to use them as a conditioner to improve the organic fraction and porosity of soil. Applying SMS to fields and lawns nourishes vegetation, improves the aeration and water-holding capacity of soil, decreases soil erosion potential, and promotes the growth of beneficial soil organisms (PADEP 2000).

Unfortunately, many SMS or wastewater management systems do not fully utilize the nutrients in SMS. Applying SMS or wastewater either in excess, at the wrong time, or otherwise handling them improperly, releases nutrients into the air and water. Instead of nourishing crops, nutrients may leach into soil and groundwater. One common mistake is the practice of applying commercial fertilizer in conjunction with SMS, without accounting for the nutrient value of SMS itself (PADEP 2000).

SMS is often applied directly to an existing crop (e.g. hay) as either a mulch or fertilizer. Due to the physical characteristics of SMS, its nutrients are in a more stable form than those in raw ingredients and manure. They pose less threat to surface water resources, if reasonable care is taken to avoid application to areas where erosion is likely.

Application of SMS to Non-Agricultural Land

A number of research papers that we reviewed examined the potential of using large quantities of SMS for reclamation of mined land, as a substitute for topsoil in landscaping and construction projects, or as a material for wetland restoration.

All of these uses are potentially valuable and interesting outlets for the solid by-products of mushroom farming. In the case of mine reclamation, the potential utility of organic material is enormous, particularly if the mine site and mushroom farm were in close proximity to one another. This use could constitute steady demand for farm wastes.

An in-depth examination of the potential for using mushroom substrate to restore mine lands would include cost-benefit analyses of the various transportation options. For instance, it would be prudent to consider using existing rail lines as a means of moving SMS to the mine. Because mine reclamation is a heavily regulated activity, developing a restoration strategy that incorporates mushroom farm waste would require close coordination between industry and the relevant regulatory agencies.

The demand for other potential non-agricultural uses of SMS – for landscaping of construction sites and large land developments like golf courses – is likely to be sporadic in nature. Furthermore, if SMS is to replace traditional materials (fertilizer and topsoil) its use will have to demonstrate cost advantages.

LONG-TERM SOLUTIONS

As discussed in the preceding sections, mushroom farming offers numerous attractive possibilities for green twinning between the mushroom farm and other businesses and industries that produce organic wastes. Most of the uses for SMS that we investigated are either seasonal or sporadic in character. For example, a golf course would only be a one-time user for SMS and the demand for potting soil is generally seasonal. Additionally, one of the biggest challenges to devising alternative uses/solutions is that the majority of SMS residue is concentrated geographically. In 1998, for instance, 40% of all mushrooms grown in the United States were produced in limited regions in Pennsylvania and California (USDA 1999). It is hard to say if this concentration benefits or hinders the maintenance of industries that reuse SMS, but certainly in the case of some uses, the supply far outstrips the local demand.

Additionally, one of the biggest challenges to devising alternative uses/solutions is that the majority of SMS residue is concentrated geographically. In 1998, for instance, 40% of all mushrooms grown in the United States were produced in limited regions in Pennsylvania and California.

IBS Options for Mushroom Farms

In keeping with the principles of industrial ecology and the IBS conceptual framework discussed earlier, we looked beyond the ways in which a mushroom farm might market its SMS for off-farm uses and examined ways that a farm might develop value-added on-farm processes for integrated reuse of spent substrate.

In considering this challenge, we established certain criteria to guide the development of alternatives. Any potential on-farm solution must:

- Leverage farm's infrastructure and expertise;
- Minimize additional inputs;
- Demonstrate financial viability.

Based upon these three criteria, we developed two models, which will be discussed below as the basis for further research on applying the concepts of industrial ecology to mushroom farming.[3]

The first alternative considers a method to use spent mushroom substrate to grow additional products, while the second looks at the possibility of using the SMS as an energy source for producing steam and electricity that could be used to supply the power demands for the farm.

[3] Note that as we were unable to investigate financial considerations and numbers for an actual working farm, our third criteria, financial viability, is beyond the scope of this paper.

SMS as an Input

Cultivation of Mycorrhizae

There has been extensive work done on the process and feasibility of using SMS as a substitute for peat or as a potting medium in containerized plants. Some researchers believe that SMS can be a new source of potting medium for the greenhouse industry. One reason that this would be attractive is the need for growers to obtain a uniform product. Currently, nursery growers in Eastern North America use potting materials that are shipped great distances – peat moss from Michigan and Canada, and wood bark from North and South Carolina and Georgia. If mushroom growers can demonstrate the substitutability of this product to the greenhouse industry and as long as shipping costs are not prohibitive, then it could be a valuable outlet for the industry.

The idea of cultivating mycorrhizae builds on the potential of using SMS as a potting medium. Mycorrhizae are highly valuable, difficult-to-culture fungi which facilitate nutrient uptake by green plants. Because they are fungi (like mushrooms), there are numerous similarities in their culture; however, it is commonly believed that cultivation of mycorrhizae on a large scale is difficult and expensive. Because of this, we propose the idea of creating a system for cultivating mycorrhizae in tandem with the production of mushrooms. In this manner, a mushroom farm enters the market for a new valuable product, while at the same time benefiting from numerous synergies on the production side. Such synergies might enable a mushroom farm to have lower costs, as compared to a stand-alone mycorrhizae operation. For example, a mushroom farm is likely to have the following infrastructure in place:

- Existing heating and steam generating facility;
- Steam pasteurization equipment;
- Laboratory facility for culturing mushrooms;
- Scientific expertise in growing fungus;
- Large amount of organic material suitable for growing plants (SMS).

Several other requirements for mycorrhizae horticulture must also be considered. For example, most of the appropriate fungi are obligate symbionts, meaning that they cannot be grown in pure culture. Mycorrhizae must be cultivated in the roots of green plants and, to avoid contamination, they must be grown in sterile conditions. Except for the symbiotic relationship with green plants, all of these conditions are true for mushroom farming.

Conceptually, then, mycorrhizae could be grown in greenhouses and harvested from the roots of plants grown in the spent compost from the mushroom house. The waste stream from this process would be fully composted as the green plants and the mycorrhizae further take up and use the nutrients in the SMS (See Figure 4).

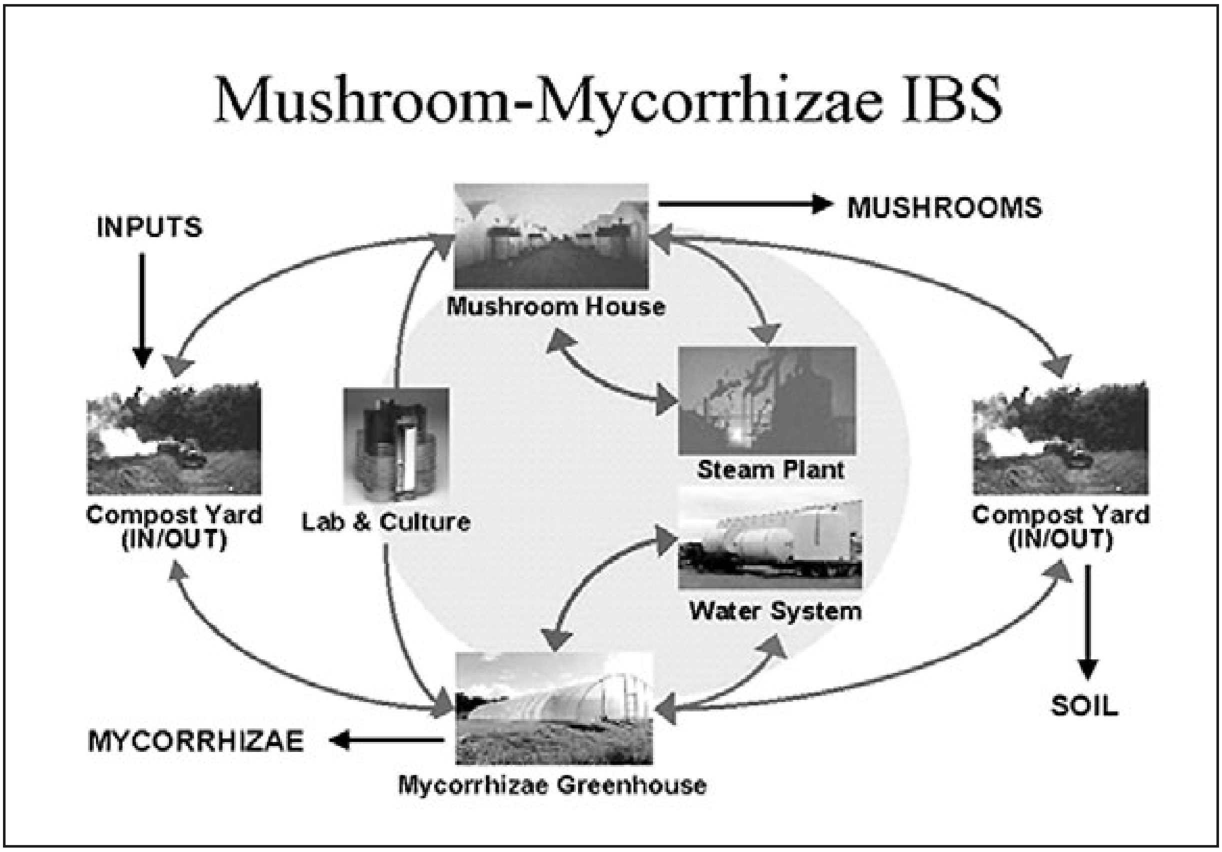

Figure 4 Mushroom/Mycorrhizae Farm

While we found several companies which are marketing mycorrhizae, suggesting that there are commercial uses for the fungus, the details of the growing process appear to be closely-guarded trade secrets. Therefore, it is difficult to realistically estimate the amount of SMS that would be diverted from the waste stream under this scenario.

Potential Markets for Mycorrhizae

Essentially, mycorrhizae are fungi (myco = fungus, rhizae = root) which attach to plant roots in order to exchange nutrients in a symbiotic relationship (Harley and Smith 1983). When a fungal spore germinates in the soil, it forms a sheath around the root. The presence of mycorrhizae can have significant effects on the morphology of a plant's root system. For instance, many fungi are capable of producing plant growth hormones that change the branching pattern of the root system (Allen 1992).

The most well-known benefit to plants from mycorrhizae is an increased uptake of phosphorous. In general, mycorrhizae will increase the uptake of any nutrients that move through the soil primarily by diffusion. The fungus is able to extend out from the root much farther than the plant's own root hair can, and thus it reaches the nutrient sooner than a root hair would. Also, the surface area of the fungus can be many hundreds of times larger than the root's (Altman 1993).

Greater surface area and reach is not the only way mycorrhizae can aid plants in the uptake of minerals. While many nutrients in the soil are in a chemical form that plants can neither absorb nor use, mycorrhizae can secrete enzymes that break down the substance extracellularly. The fungus then absorbs the nutrient and transports it to the plant, indirectly helping the plant gain nutrients (Altman 1993).

To some extent, mycorrhizae can also aid plants in drought and pest resistance, though the mechanisms involved are poorly understood. Mycorrhizae can help control pests such as pathogenic fungi and nematodes by releasing antibiotics into the soil which reduce the risk of infection. In the case of other fungi, sometimes the mycorrhizae will simply out-compete the potential pathogen for nutrients and food. Even the very presence of the mycorrhizae can trigger the plant to produce natural defenses in the root (Abbott and Robson 1984).

In addition, mycorrhizae offer benefits that could improve crop value, including increases in seedling survival rate, plant growth rate, number of flowers produced, and even the survival period for cut flowers.

Currently, the literature about the practical use of mycorrhizae suggests that it is still more expensive than traditional NPK fertilizers. However, it is also suggested that excessive fertilization is not only a costlier, but also an inferior way to enhance plant performance. We spoke briefly with Professor Graeme Berlyn at the Yale School of Forestry & Environmental Studies, whose company "ROOTS" markets a product that uses mycorrhizae. Dr. Berlyn felt that the full value of mycorrhizae might lie more in adding them to products to recover heavily degraded, eroded, or compacted soil.

Despite the current problems with commercial mycorrhizae production, some companies are producing innoculum available to both large scale nurseries and backyard gardeners and farmers. One company in Oregon (Bio-Organics 2000) sells three pound boxes of mycorrhizae spores to spread on a plant's roots during transplanting, or to mix with seed. The recommended rate is one pound per acre with an advertised cost of $25.00 per acre. There is also some potential to sell very specific mycorrhizae for particular applications; for example, a product could be developed to target just one type of crop or flower.

SMS Used as an Energy Source

Biogas Recovery
A conceptual alternative to developing another sub-system or process that uses the SMS as a supply source (i.e. mycorrhizae production) is to use the SMS as an energy source to meet the potentially high energy demands of a mushroom production facility.

One method that has potential in this application is anaerobic digestion. This concept is particularly compelling in light of the high energy and water demands of a mushroom farm. The material flows in this process are outlined in Figure 5 below.

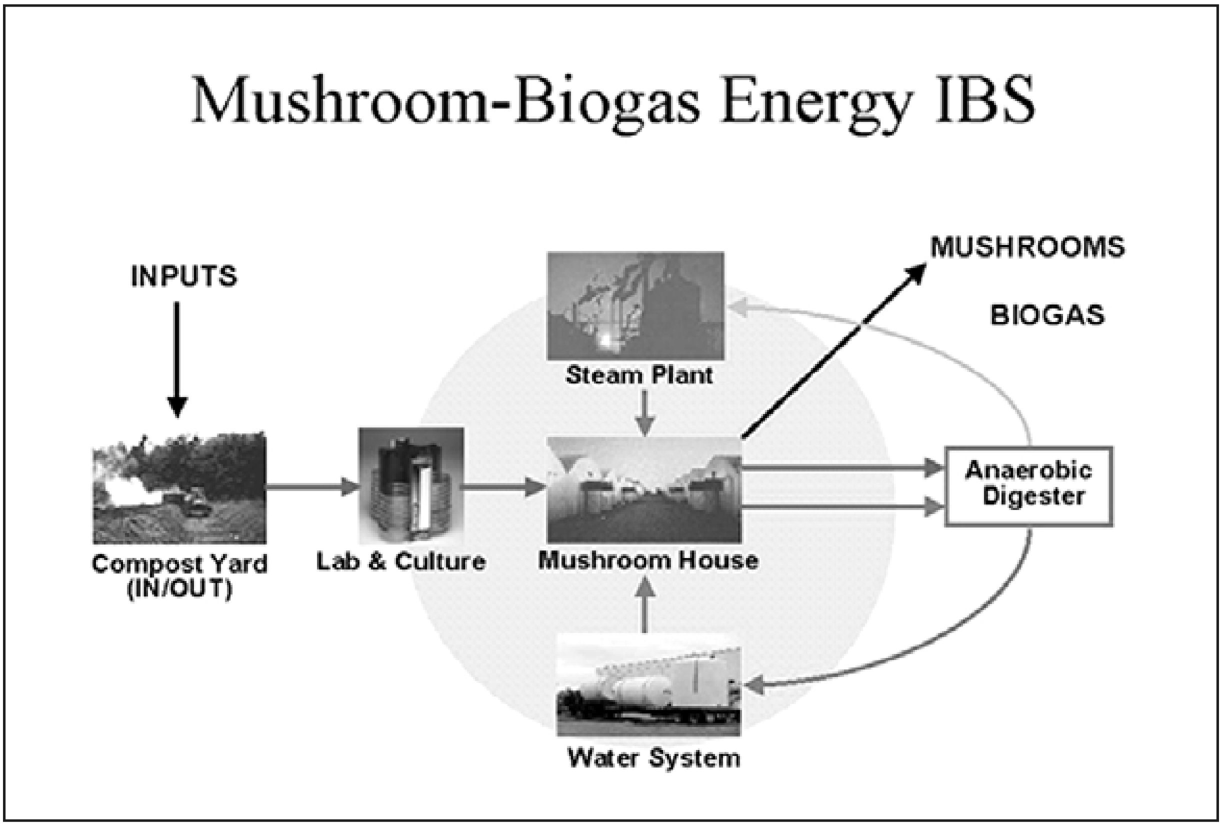

Figure 5 Mushroom/Biogas Recovery IBS

Anaerobic digestion reduces the bulk of organic waste by converting it into a relatively stable solid residue (digestate) similar to compost. Unlike composting, however, anaerobic digestion requires an oxygen-free environment and specialized bacteria.

The byproduct of this bacterial action is a "biogas," which is composed of methane and carbon dioxide. Anaerobic digestion has been used in sewage treatment for some time, and there are numerous examples of waste water treatment plants recovering biogas to meet energy demands for heat and power.

Another aspect of anaerobic digestion is that it is considered most useful for wet wastes since the water helps in the process and maintenance of the anaerobic bacteria. It is therefore likely that a digester built for a mushroom farm would have to combine the farm's water treatment capacity with a biogas plant.

A recent development is the fuel cell technology for electrical generation. Increasingly, fuel cells are being used in conjunction with biogas recovery operations at landfills to create electricity.

After SMS leaves the growing process it would move into the anaerobic digester where microbial activity begins. The steam for this process can be generated using the biogas, raising the temperature of the waste to increase the rate of degradation within the reactor. Waste degradation is also made more effective by adding a bacterial innoculum. This innoculum is supplied from either the waste stream from the reactor or from the farm's waste water. The mixed waste is then fed into the reactor, in which degradation occurs, producing a relatively solid residue and biogas. The biogas can be used for energy generation directly, or can be used to generate steam. The solid waste that is produced is de-watered before further treatment or disposal.

There are numerous designs and configurations of anaerobic digesters. Some operate at warm temperatures (about 30-40°C – the "mesophilic" range). Generally speaking, the higher the temperature, the faster the process, but thermophillic processes may be harder to control and need more biogas for heating to keep them at the required temperature. Other variations include low or high volume systems, single or multi-stage digester vessels, and continuous flow or batch processes.

The size of a digester depends on the amount of organic matter to be processed into gas and liquid fertilizer. Practically Green™, a company in Ireland, offers the following guidelines for estimating the volume and outputs of an anaerobic digester: "for a 'rule of thumb' figure, use a loading rate of six kg dry matter per day per cubic meter of digester" (Practically Green™ 2000).

Based on the production figures for a large mushroom farm that can produce a million pounds of mushrooms per month, the amount of SMS produced would be on the order of 30 metric tons per day (or 2,000,000 pounds per month). Assuming this material is 20% dry weight, using the formula from Practically Green™, we estimate that a large farm would produce six metric tons per day dry weight. This translates to a 1,000 cubic meter digester.

The production of gas and electricity from a digester is heavily dependent on the efficiency of the digester – the rate of conversion of dry matter to biogas. Practically Green™'s estimates for the efficiency of digester systems are about 50%. However, they note that for some old organic wastes, which may have already been partially composted, the gas production may be reduced by two-thirds – yielding an efficiency of 16% in the conversion of dry matter.

In most systems with electrical generation, the engine will produce about 2 kWh of hot water for each 1.7 kWh of electricity produced. Half of the hot water is needed to heat the digester. Determining the economic feasibility of building a digester would require a sound estimate of the amount of gas that would be produced from SMS, as well as a consideration of the long-term cost savings attributable to using the gas as a supplemental energy source.

CONCLUSION

From an environmental perspective, the elimination of waste represents the ultimate solution to pollution problems. For individual businesses, achieving a "zero emissions" outcome often translates into greater efficiency, enhanced productivity, and competitive advantage. Such improvements also represent "...a shift in our concept of industry away from linear models in which wastes are considered the norm, to integrated systems in which everything has its use. It heralds the start of the next industrial revolution in which industry mimics nature's sustainable cycles" (ZERI 2000). Mushroom farming has the potential to offer a zero-waste production process that contributes to this goal.

Mycorrhizae cultivation could represent a new and potentially lucrative market, in which cost savings can be achieved through synergies between the mushroom and mycorrhizae production processes. Likewise, biogas recovery provides an opportunity to realize substantial energy cost savings.

This paper identifies potential short-term and long-term options for dealing with spent mushroom substrate, the most voluminous residue of the mushroom cultivation process. In the short-term, best management practices, recycling, and certain non-agricultural uses appear to be the most feasible solutions. Long-term solutions, however, offer the possibility of developing integrated bio-systems, which combine mushroom farming with other on-farm uses for the substrate. We identified two such systems: a mushroom farm/mycorrhizae IBS and a mushroom/biogas recovery IBS. Both of these models utilize emerging, innovative technologies to make efficient use of substrate residue. In the first case, it serves as an input to another agricultural process; in the second, it is employed as a source of energy.

The addition of another biological sub-system (either mycorrhizae cultivation or biogas recovery) to the typical mushroom farming operation increases the potential to turn linear material flows into closed and environmentally-sound systems that reduce waste emissions.

In addition to environmental benefits, a mushroom farm IBS may also supply economic benefits to both the individual business and the community. For instance, the addition of another biological sub-system to an existing mushroom farm should be viewed as a business growth opportunity. Mycorrhizae cultivation could represent a new and potentially lucrative market, in which cost savings can be achieved through synergies between the mushroom and mycorrhizae production processes. Likewise, biogas recovery provides an opportunity to realize substantial energy cost savings. Admittedly, an individual mushroom farm would need to conduct a detailed analysis of these separate investments, in order to determine their operational viability and profitability.

Finally, the development of a mushroom farm IBS creates the potential for upsizing. By adding more components to the existing system, one can create new production chains, new jobs, and more diverse revenue streams. Thus, what initially was conceived as a solution to a waste problem has become a valuable tool for realizing both economic and environment gains.

REFERENCES

Abbott, L.K., and A.D. Robson. 1984. The effect of mycorrhizae on plant growth. In C.L. Powell and D.J. Bagyaraj, eds. *VA mycorrhizae*. CRC Press, Boca Raton, FL.:113-130

Allen, M.F., ed. 1992. *Mycorrhizal Functioning: An Integrative Plant-Fungal Process*. Chapman and Hall, London.

Allenby, B.R., and T. E. Graedel. 1995. *Industrial Ecology*. Prentice Hall: Englewood Cliffs, NJ.

Altman, J., ed. 1993. *Pesticide Interactions in Crop Production: Beneficial and Deleterious Effects*. CRC Press, Boca Raton, FL.

Bio-Organics, 2000, mycorrhizae innoculants, http://www.bio-organics.com/FAQs.html

Chertow, M. 1999. Industrial Symbiosis: A multi-firm approach to sustainability. Paper presented at Eighth International Conference of the Greening of Industry Network. Nov. 15, 1999.

Harley, J.L. and S.E. Smith. 1983. *Mycorrhizal Symbiosis*. Academic Press, London.

Klee, Robert. 1999. Zero Waste System in Paradise. *BioCycle Magazine*. February 1999:66.

Miller, Orson, K. Jr. 1972. *The Mushrooms of North America*. E.P. Dutton & Co.: New York, NY.

Pensylvania Department of Environmental Protection (PADEP) 2000, Best Practices for Environmental Protection in the Mushroom Farm Community. http://www.dep.state.pa.us/dep/deputate/airwaste/wm/MRW/Docs/Mushroom.htm

Practically Green ™ Environmental Services. 2000. http://www.practicallygreen.com

UNU/IAS Integrated Bio-Systems Project. http://www.ias.unu.edu/proceedings/icibs/ibs/

United States Department of Agriculture (USDA), Mushroom Statistics, Economic Research Service, Mushroom Industry Report, September 1999.

Wuest, Paul J., Michael D. Duffy, and Daniel J. Royse. *Six steps to mushroom farming*. Special Circular 268. The Pennsylvania State University. College of Agriculture, Extension Service, University Park, PA.

Zero Emissions Research and Initiatives (ZERI) Foundation. http://www.zeri.org/

Waste Equals Food: Developing a Sustainable Agriculture Support Cluster for a Proposed Resource Recovery Park in Puerto Rico
1999

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ABSTRACT
This paper analyzes and makes recommendations for plans to develop an eco-industrial park (EIP) in Puerto Rico. This project began with two basic goals: first, to supply cheaper energy to the island, which has suffered economic losses due to expensive energy; and second, to deal with the solid waste management problem. Thus, a proposal for a waste-to-energy (WTE) facility entered the picture, and close behind came an ambitious plan to convert the surrounding area into an EIP to be called the Renova Resource Recovery Park (RRRP). The EIP has been designed to include industries such as an existing paper mill, a steel casting plant, and a cement kiln. However, given the fact that the proposed site of RRRP is on abandoned sugar cane land, a new member was proposed – a sustainable agriculture cluster.

INTRODUCTION

Our team, with the guidance of consultants, sought to address three major issues: first, what is the potential synergy between a sustainable agriculture cluster and a resource recovery/energy cluster? The answer to this came from looking at the inputs and outputs of the WTE facility as well as the inputs and outputs of potential sustainable agriculture activities. Second, how can a sustainable agriculture industry benefit from renewable energy available nearby at reduced costs? Although energy derived from waste is not exactly renewable, we are confident that it will supply the sustainable agriculture cluster with enough inexpensive and reliable energy to ensure the continued operation of the different cluster members. Third, what specific support for cluster members would be required or recommended at this location and why? Based on the site of the RRRP, the background information on Puerto Rico, and the characteristics of sustainable agriculture, we have come up with several support cluster members which fall under the following categories: Energy Provider, Processing of Traditional Organic "Resources," Agricultural and Farming Activities, Processors of Organic "Wastes," Virtually Linked Industries, and Services.

After discussing the proposed support cluster members, their linkages and flows are further explored. We have classified these flows into four distinct groups: steam and electricity, water and liquid residues, organics and biomass, and socio-economic.

Upon analysis of the whole project, certain stages of development, which reflect our short-term, medium-term, and long-term goals, were determined. The process of laying out these goals was done by first identifying and prioritizing those cluster members that had to be put in place at the onset; second, by adding in the other members which would provide additional support to the cluster through their functions and flows; and finally, by envisioning an ideal scenario for RRRP, one that aims for the revitalization of Puerto Rico's agricultural sector, for replication to similar settings, and for sustainable development.

The final section of the paper outlines recommendations for the implementation of the project and for future study. It concludes with an evaluation of the project's life cycle stages (stages of development) and environmental impacts using a Design for Environment-style matrix. Two matrices were formulated to compare the attractiveness of an EIP linked with sustainable agriculture and an industrial park with no links to sustainable agriculture.

Patrick Mahoney, chairman of Recovery Solutions, Inc., is envisioning an eco-industrial park that is "a full scale laboratory for demonstrating industrial ecology, sustainable agriculture, and self-sufficiency" (Mahoney 1999).

BACKGROUND INFORMATION

Recovery Solutions, Inc., based in Albany, New York, selected Arecibo, Puerto Rico as the site for a planned eco-industrial park. Arecibo is located on the north coast, 45 miles west of the capital, San Juan. The island is best known for its beautiful beaches and vibrant Latin culture, but Arecibo, with a long history of industry, ranks in the top 20% of polluted counties in the U.S. The eco-industrial park that Recovery Solutions is proposing to build in Arecibo will address two key problems the island faces today. First, the project would offer an improved system of managing a portion of the 8,000 tons of waste generated on the island every day. Second, the project is designed to play a role in the revitalization of Puerto Rico's agricultural sector.

Patrick Mahoney, chairman of Recovery Solutions, Inc., is envisioning an eco-industrial park that is "a full scale laboratory for demonstrating industrial ecology, sustainable agriculture, and self-sufficiency" (Mahoney 1999). There are several reasons why he feels optimistic about his company's ambitious plan for Puerto Rico. One reason is that the island is not a third world economy, but rather just emerging as an economic entity of some significance. Another reason is that its infrastructure is still evolving, especially its solid waste management system. The island is 100 by 35 miles; all industries are reasonably close to each other. The Land Authority has 20,000 to 30,000 acres of fertile former sugar cane land and a relatively undeveloped plan for how to utilize it. The island has very limited resources and its population is becoming more aware of and concerned with environmental issues. Finally, new efficiencies are needed to make Puerto Rico competitive in the American marketplace (Mahoney 1999).

RENOVA RESOURCE RECOVERY PARK

The eco-industrial park, proposed as Renova Resource Recovery Park (RRRP), would bring a new system of solid waste management to the island. The park would serve as an alternative to the traditional use of landfills as a means of solid waste disposal. One of the many benefits of the RRRP plan is that it would minimize the need for landfills, which is of particular importance on an island with acute spatial constraints.

The RRRP would be committed to recovering underutilized resources. Some satellite industries that are currently under consideration include a metal smelter, a mini steel mill, a cement kiln, a concrete products plant, a tire recycling plant, and a paper mill. The "flagship" facility in the RRRP would be a waste-to-energy (WTE) facility modeled after the SEMASS WTE facility in Rochester, Massachusetts. The basic concept of a WTE facility is using municipal trash as an input and burning it in a high-tech incinerator to produce steam which is used to generate electricity. William Rathje, author of the book *Rubbish! The Archaeology of Garbage*, has praised SEMASS for placing "as much emphasis on efficient materials recovery and residue reduction as on energy production" (Rathje 1997). In reference to the RRRP project in Puerto Rico, Rathje wrote, "Utilizing the wastes generated by society as a source of raw materials and fuel for clean energy generation makes infinite sense" (Rathje 1997).

One of the many benefits of the RRRP plan is that it would minimize the need for landfills, which is of particular importance on an island with acute spatial constraints.

AGRICULTURAL SECTOR IN PUERTO RICO

The RRRP also offers an opportunity to play a role in the revitalization of Puerto Rico's agricultural sector. To address this issue, our group analyzed the possibilities for a sustainable agriculture cluster within the proposed eco-industrial park.

With the near death of the island's sugar economy, thousands of acres of farmland went out of production and lie fallow. Today, only about three percent of Puerto Rico's population is employed in farming. Because there is relatively little production of organic tropical fruits and vegetables, there is a potential market for these crops. The proposed site in Arecibo is located adjacent to several thousand acres of fallow former sugar cane land that can be utilized in the project.

Another reason to include a sustainable agriculture component in the design of the EIP is that the creation of a sustainable farming economy requires a support infrastructure tailored to the specific needs of low-input, ecologically based agriculture. It is unlikely that the traditional suppliers of high-input industrialized farming will make the necessary leap. RRRP will be designed as a model for low-input sustainable agriculture that also is linked with a variety of industrial processes.

PROJECT FRAMEWORK

We had three main "givens" at the onset of our project. One was that the establishment of the flagship WTE facility is Recovery Solution's first objective. The rest of the eco-industrial park is contingent upon the permitting and financing of the WTE facility. Second, there are several thousand acres of abandoned sugar cane land adjacent to the proposed site. This land is to be converted into the sustainable agriculture support cluster. Third, there is a paper mill on site that currently is not functioning but could be brought back into production if a cheap energy source became available. Having this facility already on site makes it a priority cluster member.

The core cluster members for each of the six categories that reflect main components of the sustainable agriculture cluster are:

- Energy Provider: WTE facility
- Agricultural and Farming Activities: community supported agriculture
- Processors of Organic Resources: paper mill
- Processors of Organic "Wastes": anaerobic digester
- Virtual Links: pharmaceuticals
- Service Industries: education and training

We identified four different categories of flows through the cluster members: liquids and water, organic biomass, electricity and steam, and socioeconomic. This section offers a primary framework for these flows, which ideally will lead to further feasibility studies and market analysis. Additional research in these areas will help determine the scale of each suggested cluster member and the relative impact of its flows on the rest of the system.

The third major part of the paper addresses three stages of development in the RRRP project. The three stages are: Seeds for Regrowth, Refinement and Organization, and Redesign for Fecundity. These stages suggest the relative timeline for implementation of the plan and inclusion of the different cluster members.

SUSTAINABLE AGRICULTURE SUPPORT CLUSTER MEMBERS

Energy Provider: Waste to Energy Facility

One cluster member is in its own category of "Energy Provider:" the WTE plant. This facility is an essential cluster member because it is the one that would provide low-cost electricity and steam to many of the sustainable agriculture cluster members.

Primary inputs to the facility would be municipal waste and municipal and industrial sludges. The facility would be able to process 2,000 tons of these inputs per day. The outputs from the facility include electricity, steam, ferrous and nonferrous metals, and fly ash.

The facility would be modeled after the SEMASS WTE facility in Rochester, Massachusetts. SEMASS, also known as the Cape Cod Solution, is similar to other WTE facilities in that the inputs are municipal trash and, in some cases, industrial sludges that are burned in an incinerator to produce steam, which is used to generate electricity. However, SEMASS has some advanced design features that distinguish it from other WTE designs. One feature is a shredder that breaks down the municipal solid waste into smaller pieces that burn more completely. A second feature is a magnet that separates out ferrous metals before they reach the boiler. A third feature is that bottom ash is combined with other materials to form a boiler aggregate used for construction (Appendix B).

The SEMASS WTE facility utilizes or recovers 89.5% of the material that would otherwise be disposed of in a landfill. At the end of the entire process, 76.8% of the material brought in is converted to energy, 12.7% is recovered (e.g., scrap metal that is in turn sold to suppliers), and 10.5% is landfilled. Put another way, the residues being utilized by the SEMASS facility represent 10,000 barrels of oil a day, 500 tons of steel a day, 50 tons of non-ferrous metals a day, and 900 tons of aggregates a day (Neggers 1998). William Rathje wrote, "By implementing the Cape Cod Solution, a 'zero disposal' goal is not out of the question" (Rathje 1997). This is of particular importance on an island with very limited space.

By utilizing waste as a resource, Puerto Rico would benefit from a new domestic source of fuel for energy generation, raw materials for manufacturing, and aggregates for construction.

The facility was specifically designed to minimize environmental impacts. The emissions from SEMASS regularly fall ten times below prescribed limits for contaminants (Ecological Society of America 1997). This emissions record is also far superior to most conventional fossil fuel power plants. No processed water is being discharged from the facility.

In the context of Puerto Rico's economy, the WTE facility has several added benefits. The scarcity of resources on the island creates a dependency on imports. In this situation, the economy is quite susceptible to international events and material shortages. By utilizing waste as a resource, Puerto Rico would benefit from a new domestic source of fuel for energy generation, raw materials for manufacturing, and aggregates for construction. Also, the limited land available for landfills in Puerto Rico and relatively high energy prices provide the basis for economic success as well (Mahoney 1999).

In the context of the RRRP, the WTE can play a key role mainly as a source of electricity and steam. In 1997, the SEMASS facility generated 652,471 MWH of power. Of this total, 91,347 MWH (14%) was used in-house and the rest was sold. But SEMASS is not an eco-industrial park. We can expect this number to be higher in Puerto Rico given the additional facilities that are under consideration for the RRRP. A metal smelter, mini steel mill, cement kiln, concrete products plant, and tire recycling plant are all proposed for the EIP and all require high energy inputs that the WTE facility could provide (if it would be economically feasible to use the electricity "internally," as opposed to selling it to Puerto Rico's power grid).

The sustainable agriculture cluster could also benefit greatly from the WTE facility. There would be two main benefits: first, renewable energy output would be available at reduced costs. Out of the group of sustainable agriculture support cluster members the following have electricity inputs: paper mill, anaerobic digester, food processing, ethanol, composting, services group, and aquaculture.

The second benefit to the sustainable agriculture support cluster would be steam from the WTE facility. Many of the same cluster members could take advantage of the excess heat being generated by the WTE facility, including the anaerobic digester, food processing, composting (depending on scale of the activity), ethanol production, and the paper mill.

Agricultural and Farming Activities

Farming activities constitute the motor that drives the sustainable agriculture portion of the EIP. To fulfill the requirements of sustainable agriculture in the area, we have identified six activities which strongly complement each other and promote the values of sustainable agriculture, particularly social responsibility and ecological awareness. Community Supported Agriculture (CSA) was chosen as the primary member in this category because it best exemplifies these qualities. A unique relationship between farmers and their customers allows farmers to receive direct payment for their high-quality, organic produce, while customers enjoy the satisfaction of knowing exactly where and how their food is produced. This section will also briefly touch on the six activities: livestock, greenhouses, aquaculture, cash crops, truck farming, and tree plantations.

Over the past ten years, an alternative to our anonymous food supply system has emerged – Community Supported Agriculture (CSA). Subscribers to a community-supported farm pay a seasonal, monthly, or weekly fee to receive weekly shipments of fresh produce, which varies in content according to season.

Community Supported Agriculture

Over the past ten years, an alternative to our anonymous food supply system has emerged – Community Supported Agriculture (CSA). Farms using this direct-marketing method are changing the nature of conventional food shopping, in which consumers are oblivious to where and how their food is grown (Community Alliance with Family Farmers 1997-1998). Subscribers to a community-supported farm pay a seasonal, monthly, or weekly fee to receive weekly shipments of fresh produce, which varies in content according to season. This direct transaction between farmer and consumer is mutually beneficial, for it eliminates the extra costs necessitated by a middle person and enhances security by allowing farmers to deal with known and reliable buyers (Community Alliance with Family Farmers 1997-1998). CSA reflects an innovative and resourceful strategy to connect local farmers with local consumers. It results in the following socio-economic and environmental benefits: development of a regional food supply and strong local economy; maintenance of a sense of community; encouragement of land stewardship; and honoring the knowledge and experience of growers and producers working with small to medium farms (University of Massachusetts 1999).

The origin of the CSA concept can be traced to Japan in the mid-1960s, when a group of women approached a local family farm with an idea to combat the increase in imported foods, ongoing loss of farmland to development, and migration of farmers to the cities. Their goal was simply to provide their families with fresh fruits and vegetables. The farmers agreed to provide produce if multiple families made a commitment to support the farm. A contract was then drawn and the "teikei" (literally, partnership; philosophically, "putting the farmer's face on food") concept was born (VanEn 1995). Europe adopted the practice at about the same time, but the CSA movement in the U.S. was not established until 1986. Jan Vander Tuin in Massachusetts and Trauger Groh in New Hampshire created the first CSAs in the U.S., based on European models. There are currently around 600 CSAs in the U.S. and Canada (Appropriate Technology Transfer for Rural Areas 1997).

There are four types of CSAs (Bauermeister 1997):

1) Subscription or farmer-driven: the farmer organizes the CSA and makes most of the management decisions. The shareholder/subscriber is not very involved in the farm.
2) Shareholder or consumer-driven: consumers organize the CSA and hire the farmer to grow what they want.
3) Farmer cooperative: a kind of farmer-driven CSA in which two or more farms pool their resources to supply customers. This may allow the CSA to offer a wider variety of products.
4) Farmer-consumer cooperative: the farmer and consumer co-own land and other resources, working together to produce the food.

In all CSAs, the farmer develops a crop plan and a budget that details costs for a growing season and fair wages for the farmers. These are then studied and approved by the CSA membership. Costs are divided among the number of shares to be sold. Sometimes a voluntary sliding scale is used so that some higher-income households may pay more per share than lower-income households (Dyck 1992).

What are the benefits of CSAs? First, CSAs deliver very fresh, organic produce. Produce is grown without the use of synthetic fertilizers, herbicides, and pesticides and is distributed within 24 hours of picking. Second, compensation goes directly to family farms. In a conventional market system, only 25 cents of every food dollar goes to farmers, whereas in a CSA, the entire dollar goes to the farmer. Third, consumers are introduced to new varieties of produce. CSAs typically supply many different varieties of fruits and vegetables, including hard-to-find "heirloom" varieties. Fourth, customers' food dollars have a positive effect on local, ecologically-sound agriculture. In contrast, large-scale, conventional agriculture is highly energy-intensive, depletes non-renewable resources like topsoil, and contributes to lowering water tables and groundwater pollution. Finally, customers benefit from a sense of reassurance, knowing their food was produced organically with minimal impact on the environment (Food First Information and Action Network 1997-1998).

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Indeed, CSA is a perfect fit in a sustainable agriculture support cluster. Not only is it environmentally sound, it is also socially and financially beneficial.

The mutually supportive relationship between local farmers, growers, and subscriber-members helps create an economically stable farm operation and an enhanced sense of community (University of Massachusetts 1999).

Livestock

Livestock rearing is practiced by both large and small producers of high-incomes and low-incomes (UNDP 1996). While Puerto Rico imports a large share of its food, dairy, and livestock, production of chickens, cattle, and pigs is one of the leading agricultural activities on the island.

There are two scales of livestock production that can be practiced by RRRP – micro and large livestock. The former is now seen by many as an important technology for sustainable development, because small animals (rabbits, guinea pigs, etc.) are generally more efficient at converting feed to meat than large animals. Moreover, they require less space, are cheaper to feed, and are prolific breeders. Livestock provide a source of skin and fur for sale in the local market and generate dung, which can be used directly as fertilizer for gardens or treated first with anaerobic digestion or composting (UNDP 1996). Large livestock production, which usually requires vast open spaces and grazing lands, can also be done non-traditionally. The animals can be produced at high densities in "zero-grazing" (stable-fed farming) systems, where fodder is brought to the animal instead of the animal being taken to graze. Zero-grazing has many benefits as a symbiotic link in the cycle of sustainable agriculture (UNDP 1996). These benefits may include the use of other plants not found on grazing land for feed; the ease with which dung and other animal residues can be gathered for composting or digesting; and, the space saved by non-grazing may be utilized for other purposes in the sustainable farm.

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Greenhouses

There are four different types of environmental control systems in Puerto Rico used to develop plants: greenhouses, hydroponics, nurseries, and "umbraculos" (shelters to protect plants from direct sunlight). The umbraculo is the most commonly used because sunlight is intense and drastic seasonal changes are uncommon in Puerto Rico.

Hydroponics are used to cultivate lettuce, tomatoes, cucumber, spices, oregano, and aromatic and ornamental plants. In Arecibo, coriander and lettuce are the main products of hydroponic operations.

Greenhouses typically grow "recao," coriander, spices, and aromatic and ornamental plants. Some farmers have conducted research by cultivating certain crops of fruit and vegetables in greenhouses. However, the high cost of production has prevented these ideas from being developed.

Nurseries in Puerto Rico are numerous. They commonly develop cucurbitaceous, floral, and foliage plants, trees, and fruits and vegetables such as tomatoes, cook pepper, bonnet pepper, sweet pepper, cabbage, pumpkin, watermelon, cantaloupe, eggplant, papaya, and cucumber. In many cases, nurseries and greenhouses are also used for insect control.

Umbraculos are used in almost any type of cultivation. Some of the crops and/or plants developed in Puerto Rico, particularly in the Arecibo region are "recao," "pascuas," ornamental plants, coriander, and ginger. Also, in the coffee industry, some farmers use umbraculos during a certain stage of crop development (Estudios Tecnicos, Inc. 1997).

The environmental control systems described above play a role in the sustainable agriculture support cluster because they ensure the proper growth and production of plants and crops. These crops will generate income for farmers and agricultural entrepreneurs; serve as feed for animals, as input to food processing and pharmaceutical plants and the paper mill; and provide the organic residues and wastewater used in the anaerobic digester, on farmland, and in Living Machines™, wastewater purification systems described later.

Aquaculture

The food chain will not be complete if we discount aquaculture, a source of fish and seafood, aquatic vegetables, seaweed, and fodder. Aquaculture takes place in manmade tanks or in ponds, lakes, rivers, estuaries, and bays from tropical to temperate climates. Fish and water vegetables can be raised in wastewater of lower quality than drinking water. In many cases, the process of raising these crops purifies the wastewater to a cleaner state than some current sources of potable water (UNDP 1996).

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Raising fish and crustaceans in peri-urban water can be an economical complement to ocean fish and rangeland meat, conserving the global ecosystem as well as reducing consumption of energy for refrigeration, transport, and storage (UNDP 1996).

The aquaculture industry in Puerto Rico is expanding through the work of the State Veterinary Diagnostic Laboratory and the Fisheries and Aquaculture Division under Puerto Rico's Department of Agriculture. They are working towards the development of a diagnostic and epidemiological project for aquaculture and fisheries which involves education, training, funding, and the development of a laboratory diagnostic protocol for aquatic species (USDA 1997). This kind of program will provide guidance and support for the establishment and management of aquaculture activities in RRRP.

Cash Crops and Other Farming Activities

With the decline of traditional crops (sugar and coffee) in Puerto Rico due to high operating costs and dwindling markets, the emergence of modern operations and alternative agricultural crops has been observed. A growing domestic market and the potential for cost-effectiveness are major factors in the development of organic agricultural products and the use of sustainable practices in growing non-organic ones (Estudios Tecnicos, Inc. 1997).

Cash crops (high-yield crops like grains) supply the majority of food needs of the populace and account for a substantial portion of Puerto Rico's export market. Since the leading cash crops in Puerto Rico (corn, rice, wheat, soybeans, tobacco, potatoes, and cotton) may not have been developed in a sustainable manner, opportunities exist to employ more ecologically and socially responsible practices in this sector. New marketing opportunities and new technologies are being adapted by the industry. The agricultural sector is adjusting to consumers' rapidly changing dietary habits, shifting demand from tobacco, coffee, sugar, and starchy products to fruits, vegetables, poultry, and dairy (Estudios Tecnicos, Inc. 1997). One might expect the supply and demand for organically grown fruits and vegetables to be high in Puerto Rico, but it is not. Most of the products, imported from California and New York, are not supplied consistently. Furthermore, demand is affected by a lack of confidence in organic production due to the absence of regulation and possibilities for fraud (Estudios Tecnicos, Inc. 1997).

Currently, there are only two agricultural operations in Puerto Rico supplying organic products. The RRRP would face little competition in the production of organically grown herbs, fruits, vegetables, beverage crops, and medicinal crops. Establishing another venue for growing organic produce will increase its supply and hopefully, its demand and consumption as well. It will also eliminate the transportation costs associated with importation. Ecologically, this will be beneficial, since organic products do not use harmful pesticides and fertilizers that may contaminate the soil and water sources.

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Beverage crops include grapes, hibiscus, palm, tea, qat (a tea substitute), and matte (an herbal tea). These may promote new entrepreneurial ventures focusing on the postproduction processing of these plants.

Medicinal crops are another important agricultural crop. In many countries, the use of medicinal herbs such as gingko biloba, St. John's wort, echinacea, and ginseng is widespread not only as traditional cures but also for sale to the pharmaceutical industry for synthesis. Along with culinary herbs, which require similar management, medicinal crops provide an important cash supplement for small farmers. This underscores the importance of bringing nutritionists and health care specialists into sustainable agriculture studies to define opportunities and risks (UNDP 1996).

A sustainable agriculture cluster also has room for other farming activities. Those that deserve mention are apiculture and vermiculture. Apiculture involves specialized techniques of beekeeping and can often be found in periurban areas. This activity exists in Puerto Rico, but could be expanded to tap the human capital in Arecibo and promote links with the cottage industry. A labor-intensive activity, apiculture could provide many new jobs as a standalone business, or a side activity for small farms. Wax obtained as a by-product has much commercial utility, particularly as a source of lighting material. Finally, the role of bees in pollination to promote biodiversity within the cluster is clearly vital (UNDP 1996).

Similarly, vermiculture (the raising of worms) has diverse uses in the sustainable agriculture context. Some worms which may be grown in the area feed on mulberry leaves and spin commercially valuable silk. Also, the use of worms in composting (vermi-composting) greatly increases the effectiveness of the process. Lastly, worm larvae are raised as fodder, especially for chickens (UNDP 1996).

Truck Farming

Truck farming is a small-scale farming activity wherein market produce is grown and transported by truck to the city or to distribution warehouses. It makes use of a wide range of marketing modes, from grocery stores to sidewalk stands. Although truck farming is a generic concept not specific to organic practices, it would certainly be helpful for moving alternative and organic crop products to market (Lowe 1999a).

Estudios Tecnicos, Inc. (1997) concluded in its report on the feasibility of truck farming in Puerto Rico that there is an attractive market for selected products because of the dependence on imports. Such imports originate primarily from the United States, and in 1997 amounted to $135.7 million. The volume of imports suggests that there is room in the local market for a modern, efficient, and cost-effective agribusiness. Its success would depend not so much on the existence of a reliable demand for the products, but rather on its ability to be price competitive. Government support could help in this respect. Also, the support of health food stores, restaurants, and specialized supermarkets, which are potential clients for high quality agricultural produce, would be essential.

Nutrition experts are placing more emphasis on produce grown using natural approaches. We can expect that the market for these products will grow at a steady pace in the foreseeable future. Therefore, a modern and efficient truck farming activity, able to manage costs effectively, could carve itself a space in the changing Puerto Rico market (Estudios Tecnicos, Inc. 1997).

Agroforestry has substantial potential in the short term to contribute fuel, construction materials, and food. In the long term, agroforestry may be important for reducing the indirect impacts of cities on surrounding and more distant ecosystems, and for biologically processing urban wastes into clean air and water.

Tree Plantations

To further utilize the land at RRRP, we are proposing the establishment of tree plantations that would be sustainably harvested and managed. Agroforestry has substantial potential in the short term to contribute fuel, construction materials, and food. In the long term, agroforestry may be important for reducing the indirect impacts of cities on surrounding and more distant ecosystems, and for biologically processing urban wastes into clean air and water. All these functions complement the special contributions that woodlands provide to the physical and mental well-being of community residents, as trees are aesthetically pleasing, soothing, and noise reducing (UNDP 1996).

Aside from tropical fruit trees such as mango and durian, we have identified teak and bamboo as likely species to grow in such a tree plantation at Arecibo. Teak has been cultivated in the tropics for centuries. Although it is not devoid of silvicultural and management difficulties, it is a well-known timber species, relatively benign and successful in plantation environments in the tropics (Centeno 1996a). Teak is a fine timber that is not only beautiful, but also versatile, strong, dimensionally stable under outdoor environmental conditions, and resistant to weathering and biological attacks (Centeno 1996b). These characteristics make it extremely marketable; its demand outstrips supply (Keogh 1996). It grows quickly on tropical tree plantations and can be harvested as early as six years after planting.

Bamboo is a grass and the fastest growing plant known to man. Thousands of species flourish throughout the world, especially in Asia and South America. Today, bamboo is also being grown and harvested in the United States by a number of different companies in properly managed forests. In addition to bamboo's many uses as a building material, the plant in its natural living state generates more oxygen than a similarly-sized grove of trees. A small stand of bamboo can reduce the temperature in its immediate environment by as much as ten degrees (Residential Environmental Design 1998).

For developing countries, bamboo is being considered as an ecologically responsible agricultural crop. Some environmentalists are suggesting bamboo crops as a remedy for deforestation and the displacement of agriculturally based societies. Bamboo is a strong contender, and will continue to play a vital role in the production, construction, and decoration of environmentally-friendly homes of the future (Residential Environmental Design 1998).

Processors of Organic "Resources"

Traditionally, natural renewable resources such as wood from trees have been processed in ways that are both inefficient and detrimental to the environment. Recognizing the need for natural resource products such as wood products and paper products, we have attempted to rethink the processing of these materials. We have approached this at the level of natural resource production (tree plantations and fiber crops) as well as at the level of transportation, processing, and distribution of products made from these resources. Paper and lumber mills have traditionally generated a great deal of waste and have used toxic chemicals that are released throughout the life-cycle of the product, on both the production side (gaseous and liquid emissions) and the consumption side (e.g., off-gassing of formaldehyde in wood). Even recycled paper has been processed in such a way that the value of reusing old paper may be outweighed by the detrimental effects of the chemicals used in removing and separating ink and re-bleaching the paper. Recently, due to a deeper understanding of the potential hazards of chlorine and the potential of chlorinated hydrocarbons for endocrine disruption (Colborn *et al.* 1996), it has been increasingly important to develop and implement alternatives to the use of chlorine in paper bleaching and processing.

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As cluster members, the paper mill and lumber mill are important components of the eco-industrial park. The paper mill is an essential cluster member because the capacity to re-start the facility already exists. It will support a growing need for paper to be made from materials other than raw wood, to be produced without the use of chlorine, and it will provide support for a recycling infrastructure on the island. The lumber mill is an important cluster member because it will add value to the wood grown in the tree plantations, provide residues that can be used in the paper mill, provide sustainably grown wood for use in buildings in the Park, and ultimately will contribute to the mitigation of climate change (by CO_2 absorption) and the development of alternatives to old-growth cutting. Both processes contribute to the economic success of the park by adding value to raw and reused materials.

Paper Mill

In 1990, the U.S. paper industry released 111,000 kilograms of emissions into the air (mostly in the form of SO_2 and odorants, as a result of the high-temperature digestion of wood fibers in a sulfate solution, a process that generates organic sulfides); 17,100 kilograms of surface water discharges; 3,350 kilograms of releases to the land; and 8,370 kilograms of off-site transfers, making it one of the most polluting industries (Graedel and Allenby 1995). Paper manufacturing in the U.S. is also one of the largest industries, producing 71 million metric tons of paper and paperboard with a wholesale value of over $47 billion in 1988, and accounting for about $140 billion of the annual gross domestic product. The bulk consists of virgin fibers, which are superior in strength, consistency, and purity, with only 27% consisting of recycled or secondary fibers (Jeffries 1996).

Because paper is a biological material, it can be effectively modified by enzyme technologies. Enzyme-based technology is promising as an alternative to chemical processes.

This situation is changing as landfill disposal costs increase and as timber becomes more difficult to obtain. Aside from the fibers needed, the paper and pulp industries use large quantities of fossil fuels and are inefficient: one ton of paper from virgin materials requires 3.3 tons of trees and 0.4 tons of petroleum (Jeffries 1996).

Because paper is a biological material, it can be effectively modified by enzyme technologies. Enzyme-based technology is promising as an alternative to chemical processes and is currently being developed to use in the following processes (Jeffries 1996):

- modification of pulp properties such as improved fiber flexibility and fibrillation;
- decreased vessel picking from tropical hardwood pulps (creating a smoother surface);
- improved drainage in recycled fibers (which usually slow down processing by reducing drainage rate);
- specific removal of xylan for dissolving pulp manufacture;
- facilitated bleaching of kraft pulp;
- enzymatic pulping of herbaceous fibers;
- enzymatic pitch removal;
- facilitated contaminant removal from recycled fibers.

Bleaching is an important economic component, since white paper sells for more than unbleached paper. However, elemental chlorine (C_{12}) and chlorine dioxide (C_1O_2) which are traditionally used to this end, create severe environmental problems by becoming toxic and recalcitrant chlorinated aromatic hydrocarbons (including dioxin), which cause severe problems in living organisms by disrupting the endocrine system (Colborn *et al.* 1996). In many European countries chlorine bleach is not permitted as an acceptable whitening agent. Alternatives to chlorine include O_2 and H_2O_2, which are several times more expensive than elemental chlorine (Jeffries 1996). Additionally, enzymes such as xylanases can reduce chemical demand in subsequent bleaching reactions, thereby reducing the amount of chemicals needed.

Processing waste paper requires even heavier chemical applications because waste paper must first be de-inked. Toners and non-contact polymeric inks from laser printers do not disperse during pulping processes or during flotation and washing. The de-inking process involves the use of surfactants and high temperatures, which increases processing costs by $10-$100 per ton of processed pulp. Certain enzymes such as cellulases, hemicellulases, or pectinases facilitate the de-inking process, and can help remove the toner from office papers. These enzymes can replace conventional chemicals and are cost-effective to this end (Jeffries 1996).

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Global Fibers, Inc., the only paper mill in Puerto Rico, shut down operations in December, 1995, due to a depressed market and poor operating conditions (Jacobs-Sirrine Consultants 1998). The mill occupies a 25 acre site within the RRRP, and includes a Hydro Pulper (that used bagasse fiber from sugar cane waste fibers) for stock preparation shut down prior to 1993, and a 142 foot paper machine (a 1959 vintage) with a capacity of 1,200 feet per minute, and 200 tons per day (T/D). When it was in operation at partial capacity, the mill's primary product was high-cost, recycled corrugated medium, two thirds of which were exported to the U.S. mainland. Increased production of this medium in the U.S. may have been one of the main reasons why the mill had to shut down.

When in operation, the mill was running at 20 to 30% of its capacity. Even if it had produced at full 200 T/D capacity, the mill was a high-cost producer in the fourth quartile. Energy Answers Corporation proposes that the mill be restarted using the energy from waste steam from the WTE facility; this would lower the mill's energy costs by 25 to 50%, making it a third or second quartile producer. However, in order for the mill to be able to sell 200 T/D of medium (if it continues to produce this product), local sales must replace the amount previously exported to the U.S. (Jacobs-Sirrine Consultants 1998).

The economic pressures eventually resulting in the mill's shut-down were as follows: high fuel costs, extremely high electrical costs due to high rates (>$0.09/kWh) and high consumption, high labor costs due to poor machine productivity, and average material costs for a recycling operation. The mill had to purchase municipal water and diesel fuel for water pumps, but there were no effluent or solid waste disposal fees.

If the mill were operating at capacity without cogeneration with the WTE facility, the mill's cash manufacturing costs would be $258 per ton (including all materials and operating costs), which is higher than the industry average (Jacobs-Sirrine Consultants 1998). However, operating at maximum capacity, combined with purchasing steam and electricity at lower rates from the nearby WTE facility, manufacturing costs could be reduced to $196/FST, which is competitive with North American manufacturing costs (Jacobs-Sirrine Consultants 1999).

The island now has four box plants which (at capacity) would use a total of 93 T/D, meaning that the local market in Puerto Rico could not absorb more than half of the mill's potential 200 T/D output. These four box plants relied on outside sources in the past. Global Fiber's higher costs made it unable to compete in its primary market due to lower rates in the U.S. Therefore, the 200 T/D of recycled corrugated medium must find market opportunities in the Caribbean and South America. Of Latin American countries, Ecuador is the primary importer, while other countries like Mexico and Brazil are net exporters (Jacobs-Sirrine Consultants 1998).

Start up costs for the mill are estimated at $5.5 million. A start-up plan must include the following elements, according to Jacobs-Sirrine Consultants (1999):

- Experienced mill management with local influence;
- Fiber Procurement Strategy that capitalizes on Puerto Rico's OCC recovery base;
- Partnership/off-take agreements with local converters;
- Marketing plan with established sales in Latin America.

Because the market for the medium is so competitive, we propose that the refurbished paper plant could explore alternative product production. Jacobs-Sirrine Consultants (1999) recommends that recycled linerboard be produced as an alternative product that is well-suited to the machine's capabilities. We envision an expansion of paper production to include higher value paper materials (such as office paper, toilet paper, tissue paper) that could successfully enter the local market.

Alternative feedstocks for the mill include herbaceous fiber and recycled paper. Paper does not need to be made from virgin wood, and it is inefficient to reduce the structural integrity of a tree into pulp. One acre of annually grown hemp may spare up to four acres of forest from clear-cutting (Nelder 1999). One hundred percent recycled paper introduces additional problems such as lowered quality and increased chemical use, as discussed above. But the benefits of processing paper waste into new paper is indisputable. We therefore propose that the paper mill use a combination of both recycled and virgin herbaceous fibers to take advantage of the benefits of both alternatives.

Paper does not need to be made from virgin wood, and it is inefficient to reduce the structural integrity of a tree into pulp. One acre of annually grown hemp may spare up to four acres of forest from clear-cutting (Nelder 1999).

In order to use recycled paper for the paper mill, there must be an appropriate and effective infrastructure with a consistent supply. The Puerto Rican fiber market is stable and isolated in comparison to the U.S. market because there is an abundant supply of OCC from imported goods packaging. In 1995, Global Fibers, Inc. had a much lower fiber cost than companies in the U.S. (Jacobs-Sirrine Consultants 1998). In that year, the materials recovered from recycling centers in Puerto Rico included 30,783 tons of paper and 108,471 tons of cardboard (Estudios Tecnicos Inc. 1998a). Global Fibers was the only company in Puerto Rico producing materials from locally recovered paper. Currently, recovered paper is collected and some is exported but none of it is processed locally (Estudios Tecnicos, Inc. 1998a).

There are 71 recycling drop-off centers in Puerto Rico (Caribbean Recycling Foundation 1997). Three of these are located in Arecibo: one in Pueblo X-Tra, one in Plaza del Atlantico, and one in the Arecibo Mall. Arecibo also participates in the municipal blue bag/blue bin program. The Caribbean Recycling Foundation has a "Zero Solid Waste" program, and has set up programs with local industries as well as in communities. It also works with schools from kindergarten to post-graduate level, to educate about recycling issues. This work will contribute positively to efforts to collect waste paper from the island for use in the paper mill, and the Foundation may be a valuable collaborator in the project development, since it already has established links to recycling in Puerto Rico.

Kenaf and hemp have been widely researched and used as paper fibers, and are amenable to biochemical pulping (Jeffries 1996). They both grow year-round in the tropics, and are very adaptable to climatic and soil conditions. Because they have lower lignin content than tree fibers, hemp and kenaf require fewer chemicals in pulping, and are also naturally whiter, requiring either no bleach, or very little of a non-chlorine bleaching agent (Nelder 1999).

Hemp has been used as a fiber for paper for almost two millennia. Hemp can be harvested after five months and must be retted to extract the fiber. After retting, stalks are dried and broken into pieces, passed through a machine with fluted rollers, and then through revolving drums with bars which remove the woody pieces. The machines can process 3-3.5 MT of dried straw per hour, producing 0.4-0.5 MT of cleaned fiber (Purdue University 1999a). The woody portions can be used in the anaerobic digester. Climatic conditions, soil, variety, and nutrition all influence yields, but a hectare usually yields between 4.5 to 7.5 T, and fiber yield is 25% of this, or 1.1 to 1.9 T per hectare (Purdue University 1999a).

Kenaf traditionally has been used for fiber in Africa and Asia. There has been growing interest in its use as an alternative paper fiber, and it holds promise as a renewable source of industrial fiber. Like hemp, kenaf is adaptable, but does best in low elevations, between 37 degrees north latitude and 37 degrees south latitude, and in areas with long, warm growing seasons (Purdue University 1999b). Kenaf is harvested at around 12 feet, retted, and processed to separate the fibers, similar to hemp. The core fibers can also be used and marketed in soil-less potting mixes, animal bedding, packing material, organic filler for plastics, additive for drilling muds, and insulation (Purdue University 1999b).

Other alternative feedstocks for the paper mill should be explored. Paper is currently being made from banana sludge (one ton of banana sludge is equivalent to about seventeen trees), grass clippings, seaweed, old jeans and clothes, tobacco, and coffee (Nelder 1999; Costa Rican Natural 1999). These and other agricultural by-products may eventually be added to the paper-making process, which would further increase the efficiency of RRRP.

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The paper mill would utilize steam and electricity from the WTE Facility and the paper mill sludge would be processed by primary treatment or Living Machines™ and either returned to the facility as cooling water, or else processed into high-quality water for re-use in the paper mill.

The maximum demand by the paper mill of the following resource streams is as follows (Renova Resource Recovery Park 1998):

- Steam: 75,000 lb/hour @ 120 psig, 421°F (less than 12% of the annual average steam produced per hour by the waste to energy facility)
- Electricity: Total: 9.0 MW = 8% of total net electricity output from the waste to energy facility
- Straight condensing: 3.0 MW
- Maximum LP extraction: 3.0 MW
- Maximum HP extraction: 3.0 MW
- Water: 20-100 gpm
- Process water discharge: 20-100 gpm

Past emissions of the paper mill facility were 183 to 575 pounds per hour of air emissions, and 3 tons per month of solid emissions. Transportation requirements were as follows: 2 to 8 semi-trailers and 10 to 20 small carriers for incoming materials, and 2 to 8 semi trailers for the outgoing finished product.

In the RRRP, with the use of alternative paper processing and feedstocks, these emissions could be reduced and eventually eliminated. The solid wastes could be processed by the ethanol producer. Transportation could be provided by trucks run on ethanol fuel.

Lumber Mill

Demand for industrial timber is projected almost to double by the year 2020 due to population growth. Forest resources will be under additional pressure as demand increases exponentially (Centeno 1996b). There will be increased demand and market opportunities for properly managed, independently certified, quality wood, which is already reflected in the high demand for such wood by companies such as Smith and Hawken, IKEA, and the Pottery Barn (Newcomer 1999). The price of well-managed timber is expected to rise in real terms (Keogh 1996). The current supply of certified wood products (less than 0.60% of world industrial roundwood) is not large enough to meet current and future demands for this product (Jenkins 1998).

Before the lumber mill is built, priority must be placed on securing the certification of plantations from a recognized independent certification organization. Certification should follow Forest Stewardship principles for sustainable forest management. Part of the business plan should be to develop a management model and philosophy according to these principles (Newcomer 1999).

> Business enterprises are making important contributions to the process of sustainable forestry. They are doing so as innovators, as

> investors, as advocates, and as leaders in institutional reforms that strengthen motives and capacities to sustain forest systems. [...] Sustainable forestry businesses must be sufficiently profitable to sustain the necessary levels of investment, sufficiently suitable ecologically to avoid depletion of nature, sufficiently responsive socially to avoid human harm and conflict, and sufficiently dynamic to learn rapidly from experience over time (Keogh 1996).

We recommend that the wood company develop a diversified base of manufacturing capabilities ranging from furniture to moldings, millwork and doors, to plywood, particleboard, and medium density fiberboard, which will allow the company to optimize the value of plantation-grown hardwood (Newcomer 1999).

Residue streams can be captured by using wood scraps and sawdust as feedstock for the paper mill, processing normally discarded cores, finger jointing normally discarded scrap, using scrap to run boilers rather than oil or electricity, and using oxen rather than tractors and sleds to transport the wood (Newcomer 1999).

Processors of Organic "Wastes"

Traditionally, farms have been viewed strictly as producers of food, including fruits, vegetables, meat, and dairy products. Materials like crop residues, animal manure, and runoff water have been thought of as "wastes" – inevitable byproducts of the food production process. In keeping with one of the fundamental principles of industrial ecology, we have learned to think of these materials not as "wastes" per se, but as "residues" with value for other processes. In order to operate our food production system in a sustainable manner, we must "close the loop" by searching for ways to utilize our agricultural residues rather than disposing of them.

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The following members of the sustainable agriculture support cluster are specifically geared toward this objective. They have in common the ability to transform resources, once considered "wastes," into valuable products that can be sold to outside markets or input to other industrial processes. Primary attention is given to the anaerobic digestion system, which shows the most promise for converting large quantities of organic residue into useful products, and in so doing, bridging the gap between the WTE facility and sustainable agriculture cluster members.

Anaerobic Digester

Anaerobic digestion refers to the decomposition of complex organic materials by bacteria in the absence of oxygen. This can occur in any anaerobic environment, but is usually used to describe an artificially accelerated operation in closed vessels. The amount of time required to process the material depends upon its composition and the temperature maintained in the digester. Mesophyllic digestion occurs at approximately 35° Celsius, and requires 12-30 days for processing. Thermophyllic processes make use of higher temperatures (55° Celsius) to speed up the reaction time to 6-14 days. Mixing the contents is not always necessary, but is generally recommended as it leads to more efficient digestion by providing uniform conditions in the vessel and speeds up the biological reactions (Anaerobic Digestion Network 1999).

Anaerobic digestion facilities have been used for the management of animal slurries for many years. They can treat any easily biodegradable waste products, including anything of organic or vegetable origin. Recent developments in anaerobic digestion technology have allowed for the expansion of feedstocks to include municipal solid wastes, biosolids, and organic industrial waste. Lawn and garden, or "green" residues, may also be included, but care should be taken to avoid woody materials with high lignin content that have a much longer decomposition time (WRF 1997a). The system seems to work best with a feedstock mixture of 15-25% solids. This may necessitate the addition of some liquid, providing an opportunity for the treatment of wastewater with high concentrations of organic contaminants.

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The digestion process adds value to the biomass through conversion into three useful products: biogas, a liquid fertilizer, and fiber. Biogas is a methane-rich mixture typically comprised of 55-70% methane and 30-45% carbon dioxide. All resultant biogas can be drawn off and recovered during the process, creating a fuel source with demonstrated value as an input for heating and cooling systems, electrical power generation, incineration processes, and transportation (WRF 1998). The digestate leaving the reaction vessels can be separated into liquid and solid fractions. The liquid, called liquor, is high in nitrogen, phosphorous, and potassium, and can be directly applied to fields in lieu of synthetic fertilizers. Its use is consistent with the principals of organic farming, as long as care is taken to apply the liquid only as needed and steps are taken to prevent runoff (Lowe 1999a). The solid fraction, called fibre, provides an excellent feedstock for composting operations described later (Anaerobic Digestion Network 1999).

It should be mentioned here that the quality of the horticultural products at the end of the process is dependent upon the quality of the material fed into the system. This is the primary drawback to including MSW, biosolids, and green wastes in the digester. They may contain high concentrations of heavy metals, pesticides, and other persistent chemicals that could preclude the use of the liquor and composted fibre as agricultural supplements for organic farming.

An anerobic digestion facility can be a large-scale, centralized plant, serving the needs of an entire community or group of farms, or a smaller operation serving an individual farm. Economies of scale favor the centralized facilities, which are able to recover their higher initial investment rapidly by treating much higher volumes of material and producing higher quantities of useful end products. Digestion plants have been built in Europe that are capable of processing up to 180,000 metric tons of feedstock per year. Experience there suggests that 15-20,000 tons per year is the smallest scale that is financially viable (Dean 1998; WRF 1998).

The boilers at the SEMASS WTE facility need to be shut down periodically for routine cleaning and maintenance. When restarted, the burners need to burn a petroleum fuel for a while as the system warms up before it can resume burning trash. In Puerto Rico, the WTE facility could be designed to burn natural gas during startup procedures. The anaerobic digester would provide an ideal source of biogass to be used for this purpose. In return, the WTE plant could provide low-cost electricity and steam for use in the stirring and heating of digestion tanks.

Living Machines™

Building on the concepts of bioremediation and ecological engineering, Living Machines™ make use of diverse life forms in new combinations of species within artificial settings for the purification of wastewater. Essentially, water carrying industrial contaminants and sewage enters the system and flows through a series of tanks filled with a complex consortium of living organisms. The tanks earlier in the flowpath typically contain unicellular microorganisms like bacteria that can feed on contaminants, chemically degrading them in the process. Successive tanks contain larger, multi-cellular organisms, such as algae and zooplankton that can uptake nutrients aiding the purification. Eventually, the water enters tanks with complex plants and animals, the right combination of which effectively removes contaminants through biological uptake and biochemical decomposition.

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These systems have been used for the advanced treatment of wastewater from municipalities, developments, resorts, and industrial parks. In the past, Living Machines™ have been successfully used to treat sewage and process waters from food processing, brewery, and cosmetics industries. Operators report the effective removal of biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), nitrogen, phosphorous, metals, and coliform bacteria. Living Machines™ are currently being used to treat well over 100,000 gallons per day in some areas, producing water suitable for irrigation, aquaculture, toilet flushing, truck washing, and other uses (Living Technologies 1999).

In general, Living Machines™ are less expensive to build and operate than conventional wastewater treatment systems. Additional income can be generated by the sale of certain ornamental plants and fish grown in the process tanks. By allowing microorganisms, zooplankton, plants, snails, and fish to breakdown and digest pollutants, the system produces less sludge than conventional systems. If the sludge is not too high in metals or other persistent chemicals it may be composted to produce agricultural-grade soil amendments by the proposed composting facility described later (Living Technologies 1999).

This technology would be suitable for the treatment of water used by the WTE facility for washing equipment and storage areas. Treated water could be continuously returned to the plant for reuse as wash water. Any electricity needed to power lights, aerators, pumps, etc. could be purchased from the WTE facility at an adjusted price.

Ethanol Production

Ethanol is a liquid non-fossil fuel produced by the fermentation of simple sugars. The inputs for this process are extremely varied. Traditionally, ethanol was produced from the soluble, and therefore edible, sugars in molasses or corn. Since these feedstocks are suitable for human consumption, they tend to fetch a high price. Recent technological developments have enabled the production of ethanol from much cheaper sources, called "lignocellulosic biomass," the leafy or woody portions of a plant that are inedible for humans. Such breakthroughs have vastly expanded the range of suitable feedstocks for ethanol production and reduced production costs (Shleser 1994). Today, ethanol can be generated from grass crops such as napier grass, switchgrass, and sugarcane, tree crops including leucaena and eucalyptus, sweet sorghum, crop residues like corn stover, bagasse, potato waste, and citrus waste, and intriguing new sources like municipal solid waste, newspaper, yard and wood waste, and cellulosic fiber fines from recycled paper mills (Jeffries 1995).

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The conversion of biomass to ethanol is a complex process requiring several steps. Different techniques exist, but all follow the same general methodology. First, the feedstock must be prepared by crushing or grinding and is then stripped of proteins. If further processed, these proteins can be purified for use in animal feeds.

The next step is for hydrolysis to convert cellulosic materials to simple sugars. Lignin and furfural are liberated during this step. Lignin can be burned for process heat and generation of energy, or processed into specialty polymers, glues, or binders used in production of plywood and fiberboard. Furfural can be used as a selective solvent, or incorporated into resins, adhesives, and protective coatings for wood.

The third step in the process is fermentation with yeast or bacteria. This transforms the simple sugars into ethanol beer, releasing carbon dioxide in the process. The CO_2 can be sold directly to dry ice and carbonated beverage manufacturers, chemically converted into methane, or used in the production of algae for animal feeds and pharmaceuticals. Fermentation also results in stillage, the remains of the single celled micro-organisms that drive the fermentation. Stillage is rich in nutrients, proteins, vitamins, and fatty acids. It can be incorporated into fish and animal feeds, or digested anaerobically to produce methane.

There are multiple uses for ethanol. Buses and trucks that run on 100% ethanol are currently in use in many countries including the U.S., Brazil, and France. Also, most major auto manufacturers have designed "flexible fuel vehicles" capable of operating on E85, a mixture of 85% ethanol and 15% gasoline. As a gasoline additive, 10% ethanol is very effective at raising the octane rating of conventional gasolines. It is also frequently mixed with isobutylene to create another gasoline additive, ETBE. Finally, ethanol can be used to drive combustion turbines for the generation of electricity (American Coalition for Ethanol 1999; Shleser 1994).

The ethanol production facility would be well served by the steady source of electricity provided by the WTE plant. Also, excess lignin from ethanol production easily could be mixed with the refuse-derived fuel at the WTE and combusted in the boilers.

Composting

Like anaerobic digestion, composting relies upon the natural degradation of botanical and putrescible waste by the action of microorganisms. The major differences are that composting takes place under aerobic conditions and uses a much drier mixture of biomass. During the process, complex organic substances are broken down into carbon dioxide, water, and a solid residue, compost. Microbial activity generates sufficient heat to raise the temperature of the mixture to 70° Celsius – enough to kill pests, weed seeds, and pathogenic bacteria. Proper composting requires a steady supply of oxygen and water to keep the moisture content above 40%, but not high enough to fill air spaces with water, creating anaerobic pockets.

Research on this process has resulted in the identification of many possible feedstocks. Food scraps, animal wastes, soft plant material, yard waste, livestock mortalities, paper, cardstock, sewage sludge, municipal solid waste, and certain industrial wastes like pulp and paper sludge have all been successfully composted. However, the inclusion of sewage sludge, industrial, and municipal wastes may introduce heavy metals and other toxic substances that cannot easily be decomposed by the process. Like anaerobic digestion, the quality of the product depends upon the quality of the inputs. Thus, it is far better to ensure that contaminants do not mix with compostable waste if a consistent, high-quality, agricultural grade compost is sought (WRF 1997b).

Mature compost is a valuable product for agricultural and horticultural purposes. It acts as a soil conditioner, which improves soil texture, reduces soil erosion, and helps to bind nutrients that might ordinarily wash away. Secondly, compost acts as a natural fertilizer, slowly releasing nutrients into the soil. Used as mulch, compost helps to smother small weeds and keep the soil from drying out. Finally, it can be used as a substitute for peat in potting mixtures. Clearly this material would be of value to the proposed agricultural cluster, especially since the RRRP site in Arecibo is characterized as having clayey soils susceptible to erosion and containing little organic material (USDA 1999). The proposed greenhouses would also benefit from compost added to its potting mixtures. The composting facility would be able to make use of the energy provided by the WTE plant for aerating and mixing its composts.

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Virtually Linked Industries

While the conventional industrial symbiosis model focuses on the sharing of residues between co-located industries, opportunities abound for the creation of "virtual" eco-industrial parks that include remote businesses. This involves trading residues not just "across the fence" to businesses owned by separate entities, but also across a considerable physical distance (Chertow 1999). In identifying candidates for virtual linkages, we sought existing Puerto Rican industries that stand to benefit economically and environmentally from symbiosis with the agricultural support cluster.

Pharmaceuticals

Perhaps the best example of a potential virtually linked industry is the pharmaceutical industry, due to its enormous presence in Puerto Rico and high potential to pollute. The pharmaceutical industry makes use of a variety of chemical processes to generate an extremely diverse set of products. Generally, this involves the concentration and isolation of a very small fraction of initial ingredients. In Puerto Rico, there are currently 79 different pharmaceutical companies producing hundreds of products and generating over eight billion dollars in exports annually. Over 18% of all the pharmaceutical products manufactured in the U.S. are shipped from San Juan (PRIDCO 1999a).

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This amount of industrial activity and the degree of processing involved in the extraction of such a small portion of finished product makes the pharmaceutical industry very energy-, water-, and materials-intensive. It also means that these companies generate a tremendous amount of residue per unit of product. Opportunities exist for the exchange of resources between the pharmaceutical industry in Puerto Rico and the agricultural network proposed for Arecibo. Of particular interest are the organic waste streams generated as a result of certain biological manufacturing processes, like fermentation.

As an example, consider the Novo Nordisk facility in Kalundborg, Denmark. This facility uses fermentation to produce enzymes, penicillin, and insulin. As a result, it generates over 600,000 cubic meters of organic sludge and 25,000 cubic meters of yeast slurry per year. To combat this disposal problem, Novo Nordisk has turned its wastes into useful products. The yeast slurry is treated with heat and lactic acid bacteria to kill the yeast cells. Then it is sold as a high value, protein-rich additive to pig feed. The sludge, made up of microorganisms, nutrient residues, and water, is treated with heat and lime to kill all bacteria and sold as NovoGro, an organic agricultural fertilizer. Wastewater, also high in nutrients and organic material, is treated on site in an expensive biological wastewater treatment plant (Novo Nordisk 1994, 1997; West Zealand Farmer's Union 1992).

With such a large number of pharmaceutical companies doing business in Puerto Rico, and many of them using biological processes like fermentation, opportunities abound for exchanges of organic products and residues (Eberhart 1999). In fact, 21 separate pharmaceutical plants have been identified in

Arecibo and nearby cities. They produce such products as antibiotics, penicillin, medicinal oil, antihypertensives, tranquilizers, vitamins, antiseptics, painkillers, and antidiabetic products. It is likely that organic residues from these processes could be stabilized and applied to the agricultural fields in Arecibo, or treated with the proposed anaerobic digester and composting facilities. These companies might also provide a nearby market for medicinal plants and herbs grown organically in the Renova sustainable agriculture cluster.

Food Processing

The food processing industry is one of the largest industrial sectors in Puerto Rico. It is similar to the pharmaceutical industry in that it produces a wide variety of products through very specific processes. To generalize, the industry can be broken down into three major processing categories: 1) fruit and vegetable, 2) dairy, and 3) meat and poultry.

The processing of fruits and vegetables has two major components. The first is the fresh pack segment, during which produce is sorted, trimmed, washed, graded, and packed. The second processing segment involves peeling, stemming, pitting, trimming, chopping, and blanching. Depending on how the produce is to be preserved, this step may also include dehydration, brining, freezing, or cooking. Fruit is most commonly preserved by canning, freezing, or fermenting. Most of these steps require water to help transport the produce and wash the equipment. Due to its heavy load of organic material, fruit processing results in a liquid waste with about ten times the BOD of domestic sewage as well as elevated TSS. Other significant residues of fruit and vegetable processing are the solids consisting of peels, pits, cores, and trimmings. These easily biodegradable organic materials are frequently used as animal feeds. They could also be digested anaerobically or composted without difficulty (CAST 1995).

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Dairy processing involves the pasteurization and homogenization of milk, and production of other products like butter, ice cream, and cheese. No solid residues result; however, wastewater from this type of processing carries large amounts of lactose, proteins, and fat. This means elevated BOD and also fats, oil, and grease (FOG). This tends to cause problems for conventional wastewater treatment systems that do not deal well with oily wastes. Again, anaerobic digestion would provide the best option for breaking down these more complex organic materials.

Finally, the meat and poultry processing industry slaughters and processes cattle, pigs, sheep, chickens, and turkeys into a variety of meat products. The first steps of slaughtering, segregating the carcass portions, and packing the meat are shared for both fresh and prepared meat products. However, canned cooked products, luncheon meats, hot dogs, bacons, stews, and other ready-to-eat meat products require additional processing steps. Most solid residues are recovered by the industry. Meat scraps, blood, feathers, and bone are transformed into animal and pet foods. Wastewater requires extensive treatment to reduce its organic loads (CAST 1995).

Food processors will be necessary to support the agricultural cluster at Arecibo by processing cash crops for sale and export. In general they tend to add substantial value to food products. A close relationship between the food processors and the farms at Arecibo would be mutually beneficial. The farms could provide the processors with a steady supply of organically grown and raised fruits, vegetables, and livestock, while the processors could provide the farms with animal feeds, which now represent some of their process wastes.

Cottage Industries

Cottage industries are low-tech, small-scale spin-off businesses that are able to capitalize on certain materials readily available from the cluster and convert them into products for market. Some examples include the manufacture of doormats from recycled tires, glassware from bottles, desk organizers from recycled computer parts, etc. (Mahoney 1999). In researching this opportunity, we focused on manufacturing processes that could be successfully operated by handicapped individuals. This benefits the local community by incorporating all individuals, even those considered "disadvantaged," into the eco-industrial network, and extends the flow of financial resources generated by the project throughout the social unit. The best opportunity identified that is directly related to the sustainable agriculture portion of the park is the production of scented candles utilizing beeswax from on-site apiculture. These products would be non-perishable, easy to store and transport, and ideal for local sale or export.

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Services

Agriculture is intricately tied to a number of other systems, including health and nutrition, the economy, land use, ecology, infrastructure, waste management, and transport. Thus, it requires more interaction with, and is more sensitive to, the influence of civic, governmental, and private agencies than most other industries (UNDP 1996). In order to promote and fully implement sustainable agriculture, the links with these agencies are of utmost importance.

There are a number of organizations that influence agriculture and farming as a whole. These can be categorized into five groups: 1) farmers' associations, non-governmental organizations (NGOs) and other support entities; 2) local and national governments and other public authorities; 3) institutions, including independent and university research centers; 4) international development agencies; and 5) miscellaneous other stakeholders. These organizations fulfill any or all of four main roles, namely: regulation, facilitation, provision, and partnering (UNDP 1996).

Regulation of agriculture through a variety of laws, rules, policies, and programs is essential in monitoring and guiding agricultural activities, as they may have significant environmental and social impacts. Facilitation includes providing technical advice and training; brokering relationships with markets, government, bankers, and other groups; leading or supporting policy or regulatory change; eliminating constraints; providing information; and assisting in organizing.

The provision of resources and inputs is a way of intensifying the involvement of different actors in agriculture. This assistance includes supplying seeds and tools, granting access to land and water, and providing a processing facility or insurance. It can also include providing financial resources for credit, or funding for research or seed money to initiate an endeavor (UNDP 1996). Partnering occurs when there is a more intimate involvement between or among actors – a strong collaborative relationship that draws on the strengths of the partners to maximize resources and yield the greatest benefits.

For the purposes of this project, we have identified six specific types of service industries that will support the sustainable agriculture cluster, with an emphasis on education and training. We believe that education and training, aside from being at the core of all the service industries, must be undertaken early on in the development of the project in order to assist farmers, new businesses, and the community at large, and to facilitate the smooth transition from one stage to the next.

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Education and Training

Agricultural education and training are essential to the enhancement of human resources and well-being in the sustainable agriculture cluster. It is crucial to emphasize that education and training are major stepping stones to our vision of sustainability – not only within the boundaries of the RRRP and Arecibo, but also in other places where this framework of industrial symbiosis and agricultural revitalization will be replicated. Success in any enterprise depends upon the skills of people. While many improved agricultural practices are the products of modern science and technology, training and education have been an integral part of improved farming since the domestication of plants and animals (EnviroWeb 1999).

In an editorial for *Ag-Sieve* magazine, Jonathan Landeck (1999) writes that:

> Of all the tools that are used in agriculture, reading and writing are unknown to many farmers, with 80-90% of farmers illiterate in some regions. Literacy is a different kind of tool which every farmer must be equipped with – it is unique in that its value improves, rather than depreciates, with use and time. That quality is a hallmark of sustainability and regeneration.

Farmers with access to the best management tools and skills are those who will survive and thrive in tomorrow's agricultural world. To be truly modern and sustainable, our world agricultural system needs educated farmers who can read and write. Likewise, modern world agriculture must reserve and use its resources to educate the non-farming agriculturalists who serve farmers.

The conduct of research by universities and independent research centers, based both locally and outside the country, is essential in educating and training farmers and agriculturalists alike. Research is a catalyst for the development of sustainable agriculture; it provides a clearer understanding of the industry's contributions and limits. Without this knowledge, credit and investment will be difficult to attract (UNDP 1996). The most pressing research need is to develop tools to eliminate the constraints that hinder sustainable agriculture's development and solve the problems associated with current practices (UNDP 1996).

An important way to expand research in this field is through surveys, both baseline and farming system. These are needed to generate data on the current state of sustainable agriculture as well as projections of its future potential. These data are needed both to convince investors, supporters, and promoters of the benefits of sustainable agriculture, and as input into the process of formulating policies and interventions for this sector (UNDP 1996). Specifically, data are needed on: the extent of sustainable agriculture; the structure of the sector; demand and supply; input and output markets and links; efficiency of the production activity; technologies and farming system mix; and the nutritional, health, and environmental impacts of farming. Another approach to education is through the identification and transfer of best practices, models and technologies, primarily through technical training (UNDP 1996).

Research is a catalyst for the development of sustainable agriculture; it provides a clearer understanding of the industry's contributions and limits. Without this knowledge, credit and investment will be difficult to attract (UNDP 1996).

During recent years, there has been a noticeable increase in formal and informal training programs about sustainable agriculture in all regions of the world (EnviroWeb 1999). This is indeed good news, for the outputs of such activities are immense – more skillful farmers, more responsible non-farming agriculturalists and other stakeholders, and the empowerment of women, who have played a quiet, yet significant role in agriculture.

The offshoots of education and training, within and across sectors, will help sustainable agriculture achieve its full potential by (UNDP 1996):

- Increasing public knowledge and support;
- Building political will;
- Improving organization and communication among farmers;
- Developing a policy framework and building institutional capacity;
- Improving access to resources, inputs, and services;
- Maximizing health, nutrition, and food security;
- Achieving sound environmental and land use management.

Farming cooperatives

There is no generally accepted definition of a cooperative. Simply put, a cooperative is a business owned and democratically controlled by the people who use its services and whose benefits are derived and distributed equitably on the basis of use (Cenex Harvest States 1999). Therefore, a farmers' cooperative aims to increase the sustainability of the farming activity by reducing input costs or increasing profits, thus reducing risks. By joining into cooperatives, small operators gain economies of scale in areas such as technical and enterprise support, supply of inputs, and marketing (UNDP 1996).

Farmers often start with joint interests (e.g. common activity in a common location, similar background), then collaborate to achieve benefits, resolve problems, and protect interests. Eventually, they may formalize their association and work with outside experts to achieve these goals (UNDP 1996).

Distribution Channels

In Puerto Rico, the norm is for agricultural products to be merchandised by wholesalers who purchase products from local, domestic, and foreign producers. These distributors sell the products to food retailers, hotels, and restaurants (Estudios Tecnicos, Inc. 1997).

Although there is an emerging trend of local producers organizing and distributing their products directly to the retail market, bypassing the traditional wholesalers and driving down distribution costs (such as with truck farming and CSA), the role of distribution firms or channels in the sustainable agriculture cluster in Arecibo would not be threatened. This is because distribution firms will be tapped to handle the mass-produced, heavy, and miscellaneous other agricultural products. Cash crops, common fruits and vegetables for food processing; medicinal crops for pharmaceuticals; timber for wood processing, construction or furniture manufacturing; fish and seafood for supermarkets; by-products from apiculture, vermiculture, and the paper mill for cottage industries, are only some examples of products which need distribution channels.

An incubator at RRRP would enable the park to make new firms one of the recruitment targets, helping to strengthen Puerto Rico's economy. Many potential investors see participation in an effective incubator as a means of increasing the success rate of new ventures.

Business Incubators

The potential flourishing of new businesses and entrepreneurial activities in the RRRP would place business incubators in high demand. According to Ernie Lowe, business incubators generate value for communities, for entrepreneurs, for other businesses in the community/region, and for investors. An incubator at RRRP would enable the park to make new firms one of the recruitment targets, helping to strengthen Puerto Rico's economy. Many potential investors see participation in an effective incubator as a means of increasing the success rate of new ventures.

An incubator for business development at RRRP would provide start-up businesses with (Lowe 1999b):

- Access to venture financing, marketing, accounting, organization design, and other business services;
- Access to common secretarial, bookkeeping, and office equipment;
- Collaboration among businesses in the shared facility and with those in other local incubators;
- Access to timely information on markets and emerging technical opportunities;
- Access to training in business basics through the Workforce Training Campus and local schools;
- Mentoring from entrepreneurs in the area.

Incubators can range from profit-making entities allied with venture funds to public institutions with no financial interest in the incubator businesses. The latter model is probably preferable in this setting. In this model, RRRP staff, area businesses, government, and the community (especially environmental and labor interests) cooperate in incubator planning (Lowe 1999b).

Information System Companies

RRRP's sustainable agriculture cluster would not be isolated from technological trends. Just like any other industry, technology in the form of management information systems, networks, and databases will be tapped in order to run the cluster and its support members more efficiently. Information system companies will assist in the gathering, compilation, storage, and retrieval of electronic information related to the various agricultural actors and the functions they perform. The pieces of information will serve as tools for effective organization and management of resources in the park. By using these tools, productivity, profitability, and employee morale may be improved through the easy identification of needs and problems and the development of creative solutions (Access Information Associates 1996). Additionally, information system companies have the capability to set up an agricultural database which may contain useful figures on crop production, farm locations, equipment, and the like. Over time, these companies may also assist farmers in practicing precision agriculture, a technique which makes use of a global positioning system (GPS) to determine the characteristics and needs of a certain patch of farmland.

Consulting Services

Consulting firms perform a wide range of services. These services range from preparing feasibility studies or business plans for a specified project or evaluating a new market opportunity, to transferring management and technical skills, new technology, crop varieties, and labor saving systems (Agland Investment Services 1992). Consulting firms may also do market research, public relations, publicity, and editorial services for the businesses that need them.

The RRRP would most likely make use of existing consulting firms, those that are off-site and that have a strong track record in agricultural consulting. However, there is always space for more of these, especially if the needs of the park become more specific and specialized to the workings of sustainable agriculture. RRRP will also offer its own consulting services in the future, when the industrial symbiosis-sustainable agriculture model is well-established and can be promulgated.

FLOWS THROUGH CLUSTER MEMBERS

One characteristic that sets industrial ecology apart from other environmental management systems is its emphasis on tracing materials flows through industry and the environment. The process of identifying a boundary and quantifying all flows of materials or a particular substance into and out of that system is known as materials- or substance-flow accounting (MFA or SFA). This endeavor may provide a variety of benefits. First, materials flows may provide an indicator of sustainability by shedding light on the balance between inputs and outputs. Second, the tracking of materials flows may locate hidden flows or "leaks" in the system, as well as reservoirs of products and materials. Finally, it can also be used to detect perturbations in natural cycles and forecast future impacts (Lifset 1999).

We have found this technique to be helpful in visualizing the symbiosis between industries at the RRRP. More importantly, we used materials flows as a tool to locate opportunities for additional symbiotic links. The following section does not attempt to provide a detailed, quantitative accounting of materials; instead, it represents the culmination of our efforts to trace the flows of materials through the proposed network of industrial activities.

One characteristic that sets industrial ecology apart from other environmental management systems is its emphasis on tracing materials flows through industry and the environment.

Steam and Electricity

Electricity would be utilized by almost every cluster member and would be produced in large quantities by the WTE facility. The other useful product from the WTE facility is steam. The steam would be used by the paper mill, anaerobic digester, and ethanol producer, as an inexpensive form of energy and heat. All three of these industries could benefit from this stream of heat energy because it would not only be inexpensive and renewable, but would also enter their facilities in a useful form. The paper mill running at maximum capacity of 200T/D would use 75,000 pounds of steam per hour at 120 psig, and 421°F, which is about 12% of the steam produced by the WTE facility.

Electricity would also be used in large quantities by the paper mill, ethanol producer, and anaerobic digester. Electricity use by the paper mill could total 9.0 MW, which would be equal to about 8% of total net electricity output from the WTE facility. Again, this supply of cheaper, local electricity is the main factor that would allow the paper mill to be operational again and competitive in the market.

Additionally, the lumber mill, composting (depending on what technologies are utilized), aquaculture (for the aerators and pumps), and the group of service industries (needed electricity for their offices) would benefit from electricity generated by the WTE facility. Figure 1 depicts the flows of electricity and steam within the RRRP.

Water and Liquid Residues

Puerto Rico's economic transition from agriculture to manufacturing has taken its toll on water supplies. The rapid industrialization has brought not only contamination of ground and surface waters, but also substantial depletion of aquifers, leading to saltwater encroachment (Hunter and Arbona 1994). For this reason, we have focused our efforts on designing a system to reuse and recycle water supplies in a cascading fashion between members of the proposed eco-industrial park.

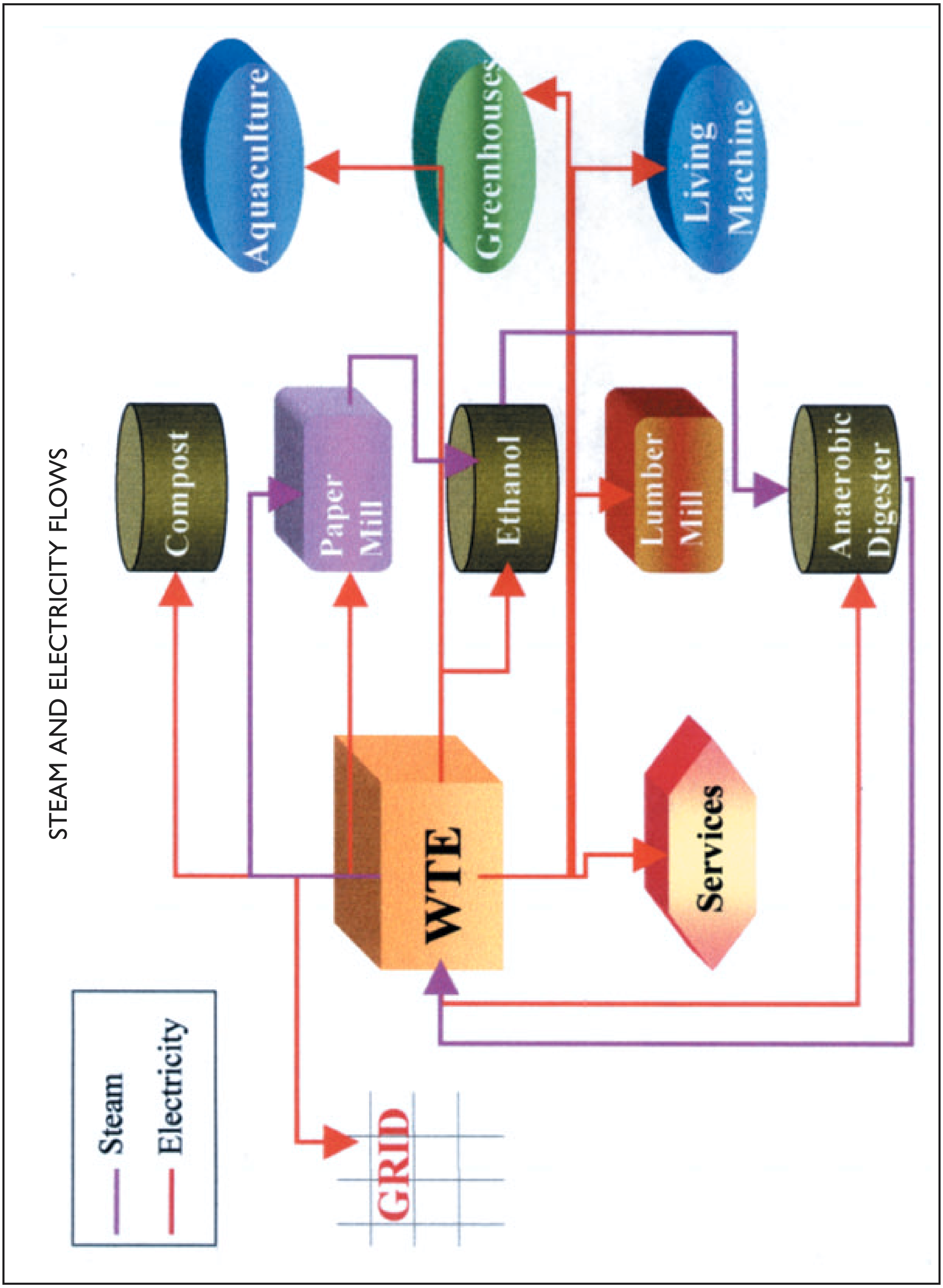

Figure 1 Steam and Electricity Flows

To accomplish this, the quality of the water needed by each cluster member was evaluated, as was the quality of the wastewater after use. Only co-located cluster members were included, since it is prohibitively costly to transport water over long distances. Four classes of water were assigned. The first is drinking quality water. The second is water contaminated with nutrients and some organic material. The third is graywater, which is water formerly used for industrial or sanitation purposes that has been treated using Living Machine™ technology. The fourth class includes effluents carrying industrial or human waste products. Using this system, several opportunities for reuse were identified and an idealized flow of water was assembled.

In this scheme, only those industries requiring drinking quality water as input draw from those supplies. These include ethanol production, the paper mill, and the services sector. Water leaving the ethanol processing facility would contain nutrients and residual organic material from the fermentation process. This mixture makes an ideal input to the anaerobic digester, where it is used to dilute solid biomass and slurries to approximately 15-25% solid material before digestion. After the organic material has been digested and converted to biogas, the remaining liquids contain only high concentrations of inorganic nutrients. To take advantage of this attribute and recycle those valuable nutrients, the liquid can be applied to agricultural fields as an organic fertilizer.

The rapid industrialization has brought not only contamination of ground and surface waters, but also substantial depletion of aquifers, leading to saltwater encroachment (Hunter and Arbona 1994). For this reason, we have focused our efforts on designing a system to reuse and recycle water supplies in a cascading fashion between members of the proposed eco-industrial park.

Water used in the manufacture of recycled paper products, and that used for cleaning of machinery and storage areas in the waste-to-energy plant, would become contaminated with a variety of industrial chemicals. This water is unfit for reuse in other processes, but can be treated to a much higher quality graywater by the Living Machine™. This graywater could be returned to the waste-to-energy plant for use as wash water, sent to the services sector to be used for flushing toilets and washing delivery trucks, or fed to the aquaculture ponds. Service businesses also need a supply of drinking water for their employees. This and the graywater used in toilets leave the businesses as sewage that is sent to the Living Machine™.

The advantage of this system is that each user is supplied only with water of the quality that it needs to have. No drinking quality water from an overburdened aquifer is wasted for flushing toilets or washing equipment. Feedback loops after treatment allow wastewater to be effectively recycled for these purposes. This relieves some of the strain on drinking water supplies and reduces the need for groundwater abstraction. Figure 2 depicts the water and liquid residue flows in the RRRP.

Organics and Biomass

Organic materials will be produced in constant supply in all of the agricultural activities: community supported agriculture, greenhouses, truck farming, cash crops, aquaculture, livestock, and tree plantations. All of the plants are processed to extract the desired product (whether it is fresh or processed plant food, medicines, or lumber), resulting in different types of organic residues. These residues can then be processed further to provide fuel energy, food for

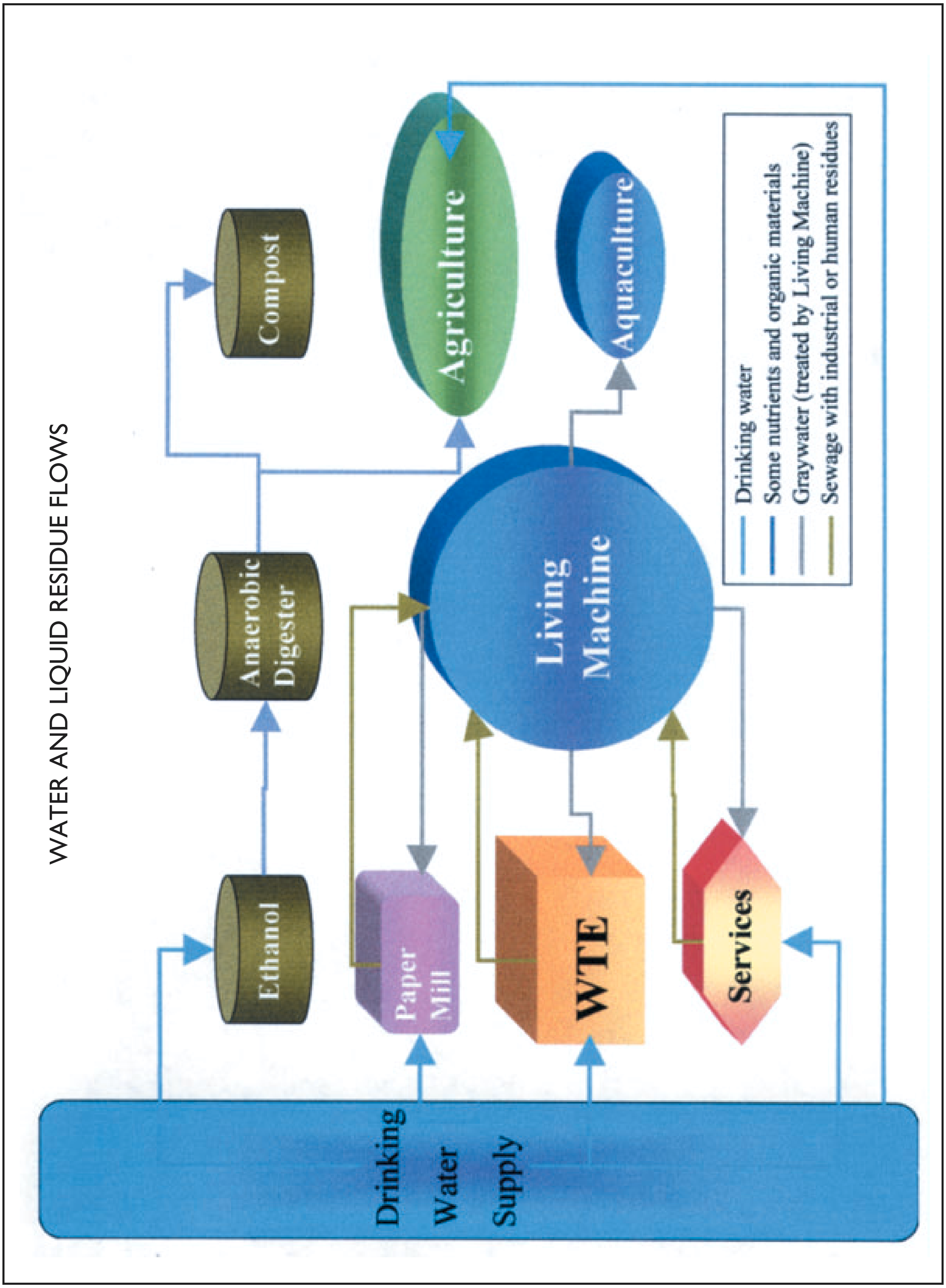

Figure 2 Water and Liquid Residue Flows

other animals, or a form of organic material that can easily be reapplied to and reabsorbed by the land.

From farming activities, consumable fresh vegetables, fruits, grains, legumes, herbs, dairy products, and meats will go directly to community members, markets, or food processing plants. Medicinal crops will be sold to pharmaceutical companies and processed into medicines.

Plant residues from harvesting, food processing plants, and pharmaceuticals then can be processed by the following (depending on suitability of material, location, and load): anaerobic digester, ethanol producer, or composter. Animal residues will go to the anaerobic digester or to aquaculture. Materials with high lignin content should go to the ethanol producer.

Trees harvested from the plantations will go to the lumber mill to be processed. About 50% will be extracted as high value lumber and sold to the market, or used in cluster member buildings. The other 50% will be chips, scraps, and shavings which can go to the paper mill, or the ethanol producer (but not to the anaerobic digester). Any fiber wastes from the paper mill can also go to the ethanol producer. The herbaceous fiber crops, kenaf and hemp, will be processed, and the extracted fiber will be made into paper, while the other woodier parts of the plants can be processed by the ethanol producer.

Ethanol can be used by farm and distribution vehicles, and any not used by the park can be sold. Lignin from the ethanol producer can be processed into binders used in production of plywood and fiberboard, and furfural can be incorporated into resins, adhesives, and protective coatings for wood. Stillage, from fermentation in the ethanol production process, can be incorporated into fish and animal feeds, or digested anaerobically to produce methane.

Biogas from the anaerobic digester can be used as input for heating and cooling systems in office buildings, electrical power generation, incineration processes, and transportation (farm and distribution vehicles). Fibre, another product of anaerobic digestion, is a quality feedstock for composting. The nutrient-rich liquid fertilizer from the digestate can be applied directly to fields in lieu of synthetic fertilizers.

Composted materials can be applied directly to farm lands to increase productivity and close the nutrient loops.

STAGES OF DEVELOPMENT

We have split the development of the Agricultural Support Cluster into three distinct stages of growth, representing a prioritization of relative importance of the member to the overall success of the resource recovery park, including such considerations as cost and market opportunities. The terms growth and development will be used in describing the stages – growth, to imply the expansion of the network in the RRRP, and development, to imply the improvement of the Park's state (Graedel 1999b). The stages identified reflect the short-term, medium-term, and long-term goals of the project.

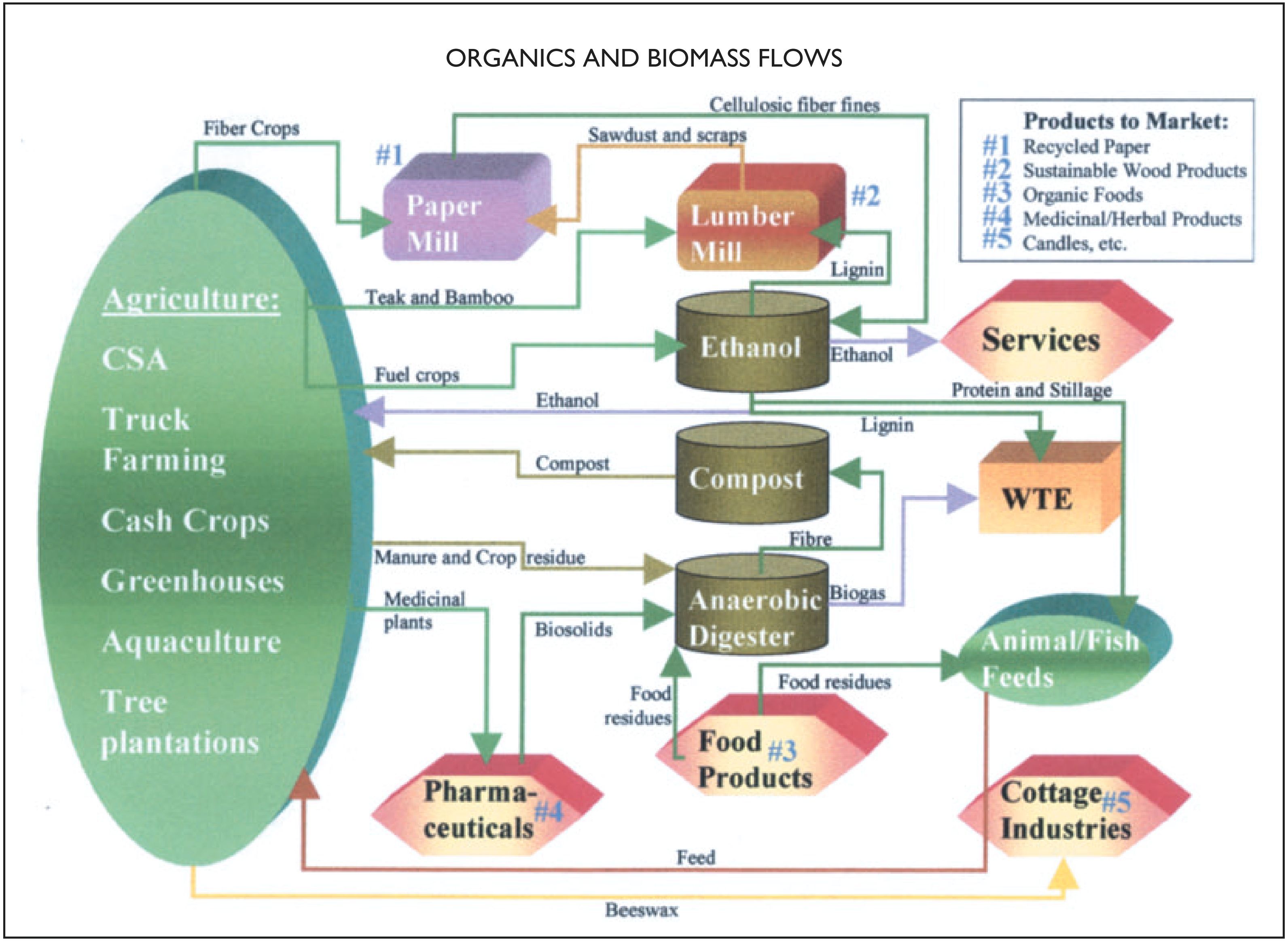

Figure 3 Organics and Biomass Flows

Initial Stage: Fallow

Fallow is defined as idle land, not currently tilled or plowed. This describes stage zero of our project, which represents the existing conditions in Arecibo and the land planned for the RRRP. At this stage, there is an idle paper mill and pulping machine, degraded farmland from industrial sugar cane production, and concrete plans for the development of a waste to energy facility. Additionally, resources include a nearby water body and human capital, including the people currently working on developing the project.

At this stage, efforts should continue to be made to recruit human capital and creative input, through education and training services, from USDA, PRDA, universities, and community colleges. Since only three percent of the population is now in agriculture, it is important to focus on the recruitment and training of farmers to work the land (Lowe 1999a). Training programs should be conducted to educate recruits and laborers in operating a farm as a business. This outreach and training is essential for the success of a revitalized agricultural sector in Puerto Rico, and in the transition from traditional to sustainable farming practices.

Stage One: Seeds for Regrowth

We have named the first stage of development Seeds for Regrowth: the seeds being the priority and initial cluster members that will be established. This first stage, which would last for about five years, focuses on the prioritization and development of core cluster members that we consider as essential to economic development and efficient symbiosis.

During this stage, the WTE facility would be built, establishing a reliable supply of energy for the rest of the operations in the Park. By providing energy in the form of electricity and steam at lower costs, the facility would contribute positively to the growth and economic success of the other proposed and possible industries in the Park (as exemplified by the paper mill analysis above). The paper mill will also be operational by the end of this stage.

Efforts should be concentrated in the development of agricultural practices that will involve continued recruitment of farmers, training and education, and testing of cultivation practices. The field crop feedstocks, hemp and kenaf, should be tested in cultivation to determine their viability as feedstocks for the paper mill. Tree plantations should be established during this stage to contribute to the restoration of the degraded land, as well as to initiate the development of and investment in future sources of capital.

Community supported agriculture would be the primary type of agriculture developed at this stage because of its small scale suitability for experimentation and testing, and immediate contribution to the vitality and well-being of local communities. In addition to education, outreach, and training services, business incubators should be in the first stage of operation, to generate value and opportunity for communities, entrepreneurs, businesses in the region, and investors, by enabling the park to attract new firms. Investors see incubators as potentially increasing the success rate of new ventures, allowing local entrepreneurs to have more access to capital than otherwise available (Lowe 1999a).

The anaerobic digester and composting facilities should be built at this stage to fill a much needed niche in the park, processing organic and livestock residues, returning nutrients to the land, and restoring degraded soil.

Finally, a "champion" organization for the land redevelopment process should be found and created outside of Recovery Solutions to organize the flexible network of businesses.

Stage Two: Refinement and Reorganization

The medium-term activities for the project, which would take place after the completion of the first stage within a period of five to fifteen years, emphasize the refinement of flows between cluster members added at stage one, the incorporation of remaining possible support members to facilitate the development of sustainable farming, and the closing of important material and nutrient loops. At this stage there will be an expansion through virtual linkages to existing Puerto Rican industries and the further development of internal and external support services.

The proposed cluster members to be added at this stage would enhance the success of the park by increasing industrial diversity and stability, and refining the cycle of flows. However, the cluster members proposed at this stage are not vital to the Park's existence, and are proposed as possibilities for valuable further developments.

This stage would include the addition of ethanol production, including the purchase of vehicles that can run on ethanol fuel for use by farms and distribution firms. The lumber mill may also be added now to prepare for the harvest of some of the fast-growing tree species that can be used at six years of age (Newcomer 1999).

Greenhouses, aquaculture ponds, and Living Machines™ may be added to support agricultural and human activities, reuse residue streams, and create valuable products like fish, ornamental flowers, and graywater. Other agricultural developments may include the expansion into truck farming, cash crops, farming co-ops, and apiculture. Cottage industries will be developed locally with the support of business incubators.

Virtual linkages would be established with the food processing and pharmaceutical industries. Services added at this stage would include the establishment of a distribution firm suited to handling the distribution needs of the cluster members, information systems, and consulting to outside projects interested in the model provided by RRRP. By the end of this Refinement and Reorganization stage, all possible cluster members should be identified, their links established, and the benefits derived from them realized.

Stage Three: Redesign for Fecundity

Fecundity is a term used to describe fruitfulness, productivity, and proliferation. It defines a system wherein there is always a potential for something new to be born, used, and reused. As we move towards the Next Industrial Revolution, the project will have to adapt to these future changes. This stage, at fifteen years and beyond, describes our vision for sustainability. This vision seeks to revitalize the agricultural sector in Puerto Rico, establish a concrete role for sustainable agriculture in eco-industrial parks, and serve as a model for similar developments.

We have used the term "fecundity" as it is described by William McDonough (McDonough and Braungart 1998; McDonough 1999), who describes a vision that looks beyond sustainability, and that models itself after the abundance in nature:

> Consider the cherry tree. It makes thousands of blossoms just so that another tree might germinate, take root, and grow. Who would notice piles of cherry blossoms littering the ground in the spring and think, "How inefficient and wasteful"? The tree's abundance is useful and safe. After falling to the ground, the blossoms return to the soil and become nutrients for the surrounding environment. Every last particle contributes in some way to the health of a thriving ecosystem. "Waste equals food" – the first principle of the Next Industrial Revolution.

We foresee an improvement in the reduction and recovery of waste streams through policies such as take-back programs and extended producer responsibility, which will eventually reduce much of the need for waste-to-energy processing. This will pave the way for the use of truly renewable energy sources and for redesigning the system accordingly.

Fuel cells for power generation may play an important role in the next decade and beyond. Currently, there is one commercially viable fuel cell power plant on the market, the ONSI PC25TM (Cler 1999), which is fueled by natural gas or propane. This may be a possibility for the use of biogas from the anaerobic digester, exemplifying how flows may be affected by a switch to this type of renewable energy source. Local integrated resource planning as a new planning approach will facilitate more informed business decisions, resulting in higher asset utilization, lower overall costs, and enhanced customer service, by addressing the needs of the customer instead of those of the generator (Lenssen and Newcomb 1999).

Equally important to our vision is the practice of truly sustainable agriculture wherein the food needs of the present and future generations are met, the environment is not degraded, and farming activities are socially responsible. All these criteria must be embodied in systematic, sensible, and just laws and policies that can be easily implemented and enforced.

Finally, our vision includes a broader societal understanding and practice of the principles of sustainable human and environmental development.

RECOMMENDATIONS AND CONCLUSIONS

Recommendations

In this paper we have included detailed descriptions of which sustainable cluster members should be included in RRRP and why. We have also presented some of the major flows that would result from the inclusion of these cluster members and, finally, a proposal for the stages of development for implementing this ambitious project.

We hope that this paper has provided insight into how to address the issue of incorporating a sustainable agriculture support cluster within an eco-industrial park. The paper has also been intended to spur additional research that will dovetail with the analysis presented here. The following are specific recommendations for further study that may help in the implementation of the project:

- Additional feasibility studies and cost/benefit analyses for each cluster member presented in this paper in order to make a final determination of which ones to pursue.
- Further analysis of export and domestic markets for products that could be generated by the sustainable agriculture cluster is also recommended. This additional research will help to pinpoint the relative scale of each cluster member and its priority level in the RRRP plan.
- Analysis of the political context in Arecibo, which may include existing rules and regulations, or values and attitudes of the local government that may either facilitate or hinder the development of the project.
- Analysis of the social context in Arecibo, which may include people's perception of and response to new developments in the area, willingness to pay for or accept new services, extent of knowledge (formal or informal) of the principles of sustainable agriculture and industrial ecology, the value people place on the environment, and the ability of people to maintain the momentum or pace of a positive change in the community.
- Analysis of environmental conditions in the area, particularly the quality and quantity of its natural resources (water, land, air), existing environmental framework/ policy, and effectiveness of enforcement mechanisms.

Conclusions

This project began with the goals of meeting two basic needs: first, supplying cheaper energy to Puerto Rico, which has suffered economic losses due to the high cost of energy; and second, dealing with the solid waste management problem in the area. Thus, the proposal for a Waste to Energy facility and plans to convert the surrounding area into an eco-industrial park were developed.

The EIP has been designed to include industries such as the existing paper mill, a steel casting plant, and a cement kiln.
Six priority cluster members have been proposed as follows:

1) The WTE, which will make use of the wastes generated by the community and the agricultural activities to supply affordable, safe, and reliable energy.
2) The paper mill, which is already standing and can be made operational once the WTE is put in place, will process fibrous materials derived from both recyclables and fiber crops to produce quality paper products. The paper mill will yield significant economic benefits to the community through these products.
3) As its name suggests, Community Supported Agriculture (CSA) highlights the relationship between farmers and the community. This form of agriculture promotes the production of organically-grown produce which does not harm the environment. It also fosters a sense of well-being among those involved – among farmers, who earn what is due to them, and among customers, who receive fresh food and have the satisfaction of knowing where it came from.
4) The anaerobic digester would process organic residues from the agricultural activities to generate useful products such as biogas, fiber, and a nutrient-rich liquid fertilizer. These products may be used to run farming equipment, as inputs to the paper mill, and as nutrients for the farmland.
5) Puerto Rico is known in industry for the presence of numerous and large pharmaceutical plants. We propose that the RRRP take advantage of these plants by forming virtual links with them. The various medicinal crops that can be grown on the land could be sold to these pharmaceuticals for processing. This is another significant income-generating scheme. In turn, the industrial sludge from the plants can serve as input to the anaerobic digester or can be applied directly to the farmland as organic fertilizer.
6) Finally, at the heart of all the developments at the Park lies the need to continually educate and train farmers, agriculturalists, industrialists, business people and the community on the principles of industrial ecology and sustainable agriculture. Our vision of sustainability for the Park and of its being a model for other EIPs largely depends on the quality and extent of the people's understanding and enforcement of those principles.

Sustainability in this sense means the reduction, if not abolition, of waste streams through policies such as take-back programs and extended producer responsibility, and more importantly, through the initiative of individuals.

This would be accompanied by the use of a more renewable energy source, the closing of all loops, and the operationalization of the phrase "waste equals food" (McDonough 1999).

No industrial ecology project would be complete without an evaluation of its life cycle stages and environmental concerns. Thus, we have subjected our proposal to a Design for Environment-style matrix. The first matrix (Table 1) places scores of 1 to 5 (with 1 being significant impact and 5 being no impact) on materials choice, energy use, solid, liquid, and gaseous residues in each stage of development of the proposed sustainable agriculture support cluster. Our project scored a total of 60 out of 100. Moreover, it is important to note the progression from low life cycle stage scores to much higher scores in the later life stages, as more symbiotic links are developed. For the sake of comparison, we constructed another matrix (Table 2, page 344) assuming that the members of the RRRP were functioning independently of each other and agriculture was practiced in an unsustainable manner. In this case, significantly greater environmental impacts are expected, as shown by the lower total score of 31 out of 100, and very little improvement in life cycle stage scores over time.

Table 1 Renova Eco-Industrial Park with Links to Sustainable Agriculture

	Materials Choice	Energy Use	Solid Residues	Liquid Residues	Gaseous Residues	Total
Stage 0 **(site today)**	2 toxic fertilizers, pesticide use, depleted soil history	2 low energy use but fossil fuels the norm	2 municipal landfills	2 leaching from landfills and pesticides from agriculture	2 emissions from open landfills	8
Stage 1 **(0-5 years)**	2 materials used in WTE facility offset by switch to organic farming, living machines for wastewater treatment	1 "dirty" power used to build WTE facility	1 municipal landfills (same as above)	2 leaching from landfills and pesticides from agriculture; offset by organic farming and living machines	2 "dirty" power used to build WTE; offset by fallow land converted to carbon sink	9
Stage 2 **(5-15 years)**	4 green design of service facility using boiler aggregate; sustainably harvested wood	3 WTE electricity, vehicles running on ethanol, steam utilized by aquaculture	3 agricultural residues to anaerobic digester and composting facility; WTE facility an improvement over landfill but fly-ash still by-product of process	4 reduced leachate from organic farming and WTE process instead of landfills	4 WTE facility has regulated emissions, ethanol fuel for distribution vehicles	18
Stage 3 **(15+ years)**	4	3	3	4	4	18
	take back programs and improvements in recycling in Puerto Rico (helped by outreach program from Renova), fuel cell technology, light rail system					
						60/100

Table 2 Renova Eco-Industrial Park without Links to Sustainable Agriculture

	Materials Choice	Energy Use	Solid Residues	Liquid Residues	Gaseous Residues	Total
Stage 0 **(site today)**	2 toxic fertilizers, pesticide use, depleted soil history	2 low energy use but fossil fuels	1 municipal landfills	1 leaching from landfills and pesticides from agriculture	2 emissions from open landfills	**8**
Stage 1 **(0-5 years)**	1 no organic material benefit	1 "dirty" power used to build WTE facility	1 municipal landfills (same as above)	1 no benefit from organic farming or living machines	1 "dirty" fuel used to build WTE; offset by fallow land converted to carbon sink	**5**
Stage 2 **(5-15 years)**	2 pesticides and chemical fertilizer, no benefits of green design	2 WTE electricity, but vehicles NOT running on ethanol, and steam NOT utliized by aquaculture	2 benefits of WTE but no links between agricultural residues and anaerobic digester/composting facility	2 no benefits from organic farming but using WTE process instead of landfills	1 WTE facility has regulated emissions but no anaerobic digester to capture methane, fossil fuels for distribution system	**9**
Stage 3 **(15+ years)**	2	2	2 no change from Stage 2, no significant improvements to system	2	1	**9**
						31/100

Scale of 1 to 5 (1= significant impact; 5= no impact)

The Arecibo project indicates that sustainable agriculture can be a useful and invaluable component of EIPs. With the emergence of EIPs in economies similar to Puerto Rico, the prospects for replication of such a venture are immense. They promise to benefit not only industry, but also agriculture, which remains a vital sector in most parts of the world.

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REFERENCES

Access Information Associates, Inc. 1996. http://www.aiahelp.com

Agland Investment Services, Inc. 1992. http://www.aglandinvest.com

ACE (American Coalition for Ethanol). 1999. http://www.ethanol.org/buy_ethanol.html

Anaerobic Digestion Network. 1999. http://www.ad-nett.org/

Appropriate Technology Transfer for Rural Areas. 1997. http://www.attra.org/attra-pub/csa

Bauermeister, Jim. 1997. CSA - A first year's experience. *Washington Tilth*. Autumn 1997: 3, 12-15.

Caribbean Recycling Foundation. 1997. http://ourworld.compuserve.com/homepages/crf/homepage.htm

CAST (Council for Agricultural Science and Technology). 1995. Waste Management and Utilization in Food Production and Processing.

Cenex Harvest States. 1999. http://www.cenexharveststates.com

Centeno, Julio César. 1996a. Universidad de los Andes. http://www.ciens.ula.ve/~jcenteno

Centeno, Julio César. 1996b. seminar presentation. American Teak Foundation seminar: Hardwood Plantations, Investment and Sustainable Development. October 11, 1996.

Chertow, Marian. 1999. The Eco-Industrial Park Concept. Industrial Ecology, Lecture 4. Yale School of Forestry & Environmental Studies. New Haven, Connecticut.

Cler, Gerald L. 1999. The ONSI PC25 C Fuel Cell Power Plant. http://www.esource.com/publicdomain/pubs_abstracts.frame.html

Colborn, Theo, Dianne Dumanoski and John Peterson Myers (Contributors). 1996. *Our Stolen Future : Are We Threatening Our Fertility, Intelligence, and Survival?-A Scientific Detective Story*. Little, Brown and Company: New York.

Community Alliance with Family Farmers. 1997-1998. http://www.caff.org/farms/csa

Costa Rican Natural. 1999. http://www.costaricanatural.com/live/index1.html

Dean, Robert. 1998. Biogas Recovery in Denmark. *Biocycle.* February, 1998.

Dyck, Bruno. 1992. Inside the Food System: How do community supported farms work? *Marketing Digest.* August, 1992: 2.

Eberhart, Donald. 1999. telephone interview. March 22, 1999.

Ecological Society of America. 1997. *Ecological Society of America.* Volume 78, No. 1. January, 1997.

EnviroWeb. 1999. http://www.enviroweb.org/publications/rodale/ag-sieve/vol5no2.html

Estudios Tecnicos, Inc. 1997. Background Data to Study the Feasibility of Truck Farming in Puerto Rico: Final Report. November, 1997.

Estudios Tecnicos, Inc. 1998a. Environmental Justice Study for a Resource Recovery Facility in Arecibo: Final Report. October, 1998.

Estudios Tecnicos, Inc. 1998b. Updated Market Assessment for a paper mill and a steel mill in Puerto Rico: Final Report. Submitted to Recupera, Inc.

Food First Information and Action Network, Institute for Food and Development Policy. 1997-1998. www.foodfirst.org/fian/csa.htm

Graedel, T.E. 1999b. Industrial Ecology, Lecture 26. Yale School of Forestry & Environmental Studies. New Haven, Connecticut.

Graedel, T.E. and B.R. Allenby. 1995. *Industrial Ecology.* Prentice Hall: New Jersey.

Hunter, John, M. and Sonia I. Arbona. 1994. *Paradise Lost: An Introduction to the Geography of Water Pollution in Puerto Rico*: 1331-1355.

Jacobs-Sirrine Consultants. 1998. Competitive Assessment of Global Fibers - Arecibo, Puerto Rico. Prepared for Energy Answers Corporation.

Jacobs-Sirrine Consultants. 1999. Start-up Evaluation of Global Fiber's Arecibo Mill. Prepared for Recovery Solutions, Inc.

Jeffries, Thomas W. 1995. http://www.biotech.wisc.edu/jeffries/bioprocessing/bioprocess_feed.html

Jeffries, Thomas W. 1996. Enzymatic Treatments of Pulps: Opportunities for the Enzyme Industry in Pulp and Paper Manufacture. USDA, FS, Forest Products Laboratory. http://www.biotech.wisc.edu/jeffries/wolnak/wolnak.html

Jenkins, Michael. 1998. editor. *The Business of Sustainable Forestry: Analyses and Case Studies.* Sustainable Forestry Working Group. Island Press.

Keogh, Raymond M. 1996. Teak 2000: A Consortium Support Model for greatly increasing the contribution of quality tropical hardwood plantations to sustainable development. International Institute for Environment and Development, Amazon Teak Foundation.

Landeck, Jonathan. 1999. editorial. *Ag-sieve.* 1999.

Lenssen, Nicholas and James Newcomb.1999. Strategic Issues Paper VIII Integrated Energy Services: The Shape of Things to Come? http://www.esource.com/publicdomain/pubs_abstracts.frame.html

Lifset, Reid. 1999. Industrial Metabolism: Implications for Policy and Management. Industrial Ecology, Lecture 6. Yale School of Forestry & Environmental Studies. New Haven, Connecticut.

Living Technologies. 1999. http://www.livingtechnologies.com/

Lowe, Ernest. 1999a. personal communication. April, 1999.

Lowe, Ernest. 1999b

Mahoney, Patrick. 1999. letter to Marian Chertow.

McDonough, William A. 1999. Corporate Sustainability by Design. Industrial Environmental Management Spring Lecture Series. Yale School of Forestry & Environmental Studies. New Haven, Connecticut. April 8, 1999.

McDonough, William A. and Braungart, Michael. 1998. The Next Industrial Revolution. *The Atlantic Monthly.* Volume 282 No. 4. October, 1998.

Neggers, Xavira. 1998. Proposed Plant Seen as a Solution to P.R. Waste Problem. *San Juan Star.* May 25, 1998.

Nelder, Chris. 1999. http://www.betterworld.com/BWZ/9512/altpaper.htm

Newcomer, Quint. 1999. Certified Resource Manager. Comercializadora de Madera Costarricense, S.A. personal communication.

Novo Nordisk. 1994. Environmental Report, 1993. Novo Nordisk A/S, Environmental Services.

Novo Nordisk. 1997. Environment and Bioethics Report, 1997. Novo Nordisk A/S, Environmental Affairs.

PRIDCO (Puerto Rico Industrial Development Company). 1999a. http://www.pridco.com/english/success/index.html#pharmaceuticals

Purdue University. 1999a. http://www.hort.purdue.edu/newcrop/duke_energy. source: Duke, James A. 1983. *Handbook of Energy Crops.* unpublished.

Purdue University. 1999b. http://www.hort.purdue.edu/newcrop/CropFactSheets/kenaf.html. contributor: Charles S. Taylor, Kenaf International, Ltd., McAllen, TX [based on Dempsey (1975)]

Rathje, William. 1997. CEO of Banco Popular. personal communication to Richard Carrion.

Renova Resource Recovery Park. 1998. Project Description and Development Review.
Residential Environmental Design. 1998. http://www.reddawn.com/featart1-98.html
Shleser, Robert. 1994. Ethanol Production in Hawaii: Processes, Feedstocks, and Current Economic Feasibility of Fuel Grade Ethanol Production in Hawaii. Hawaii State Department of Business, Economic Development & Tourism. http://www.hawaii.gov/dbedt/ert/ethanol/ethano94.html
UNDP (United Nations Development Programme). 1996. *Urban Agriculture: Food, Jobs and Sustainable Cities*. Publication Series for Habitat II. Volume 1. UNDP: New York.
USDA (United States Department of Agriculture). 1997. Animal and Plant Health Inspection Service. http://www.aphis.usda.gov/oa/pubs/aqua0897.html
USDA (United States Department of Agriculture). 1999. Soil Survey Center. http://www.statlab.iastate.edu/soils/index.html/
University of Massachusetts. 1999. http://www.umass.edu
VanEn, Robyn. 1995. http://www.context.org/ICLIB/IC42/VanEn.htm In Context. Fall, 1995.
West Zealand Farmer's Union and National Department of Plant Production. 1992. NOVOsludge in Agriculture: Results of Experiments Conducted in 1989, 1990, and 1991.
WRF (World Resource Foundation). 1997a. Preserving Resources through Integrated Sustainable Management of Waste. http://www.wrfound.org.uk/AD-IS.html
WRF (World Resource Foundation). 1997b. *Warmer Bulletin*. 53: insert.
WRF (World Resource Foundation). 1998. *Warmer Bulletin*. 63: insert.

FURTHER INFORMATION

American Sugarbeet Growers Association. 1999. http://www.hometown.aol.com/asga/sugar.htm
Apiservices – Beekeeping Gallery. 1999. http://www.beekeeping.com/articles/vietnam
Christensen, Jorgen. 1999. Industrial Symbiosis at Kalundborg: Profitable Environmental Advantages Across the Fence. Yale School of Forestry & Environmental Studies, Industrial Environmental Management Spring Lecture Serie. February 16, 1999.
Fisher, Colin. 1999. The Future is Abundant. www.yahoo.com/Science/Agriculture/Sustainable_Agriculture
Graedel, T.E. 1999a. Industrial Ecology, Lecture 1. Yale School of Forestry & Environmental Studies. New Haven, Connecticut.
Green Mountain. 1999. http://greenmt.com/tropical.htm
Hawaii Tropical Flower Council. 1999. http://www.htfc.com/flowers.html
Illovo Sugar Limited. 1999. http://www.illovosugar.com/default1.htm
International Sugar Journal. 1998. http://www.isjuk.demon.co.uk/isj.htm
Klee, Robert. 1999. Zero Waste System in Paradise. *Biocycle*. February, 1999.
Kolodinsky, Jane M. and Leslie L. Pelch. 1997. Factors influencing the decision to join a Community-Supported Agriculture (CSA) farm. *Journal of Sustainable Agriculture*. Volume 10 (2/3): 129-141.
Lowe, Ernest and John Warren. 1996. *The Source of Value*.
Manrique International Agrotech (MIAT). 1999. http://www.lava.net/manrique
McDonough Braungart Design Chemistry, LLC. 1999. http://www.mbdc.com/mbdchome.html
Michigan State University. http://www.msu.edu
National Council of Farmer Cooperatives. 1999. http://www.ncfc.org
The Ohio Corn Growers Association. 1997. http://www.ohiocorn.org/usage/uses.htm
Pennsylvania State University. 1999. http://www.agalternatives.cas.psu.edu/introduction.html
Polak, Joost. 1997. Sustaining Profits and Forests: The Business of Sustainable Forestry. Sustainable Forestry Working Group. John D. and Katherine T. MacArthur Foundation.

PRIDCO (Puerto Rico Industrial Development Company). 1999b. www.pridco.com/english/success/ sic-search.html

Purdue University. 1999c. www.hort.purdue.edu/newcrop/default.html

Rhode Island General Assembly. 1999. http://www.rilin.state.ri.us/leg_addons/naughton/aqua/aqua11.html

Sustainable Cotton. 1999. http://www.sustainablecotton.org

Sustainable Living News: A West Coast Journal of Ecological Design. 1999. http://www.sustainablelivingnews.com/sln17/coverstory.html

Tilapia Aquaculture International. 1999. http://www.cherrysnapper.com

Todd, John and Beth Josephson. 1996. The design of living technologies for waste treatment. *Ecological Engineering: The Journal of Ecotechnology:* 6.

Todd, Nancy Jack and John Todd. 1994. *From Eco-Cities to Living Machines: Principles of Ecological Design.* North Atlantic Books: Berkeley.

Union of Concerned Scientists. 1999. www.ucsusa.org/agriculture/ag-vision.html

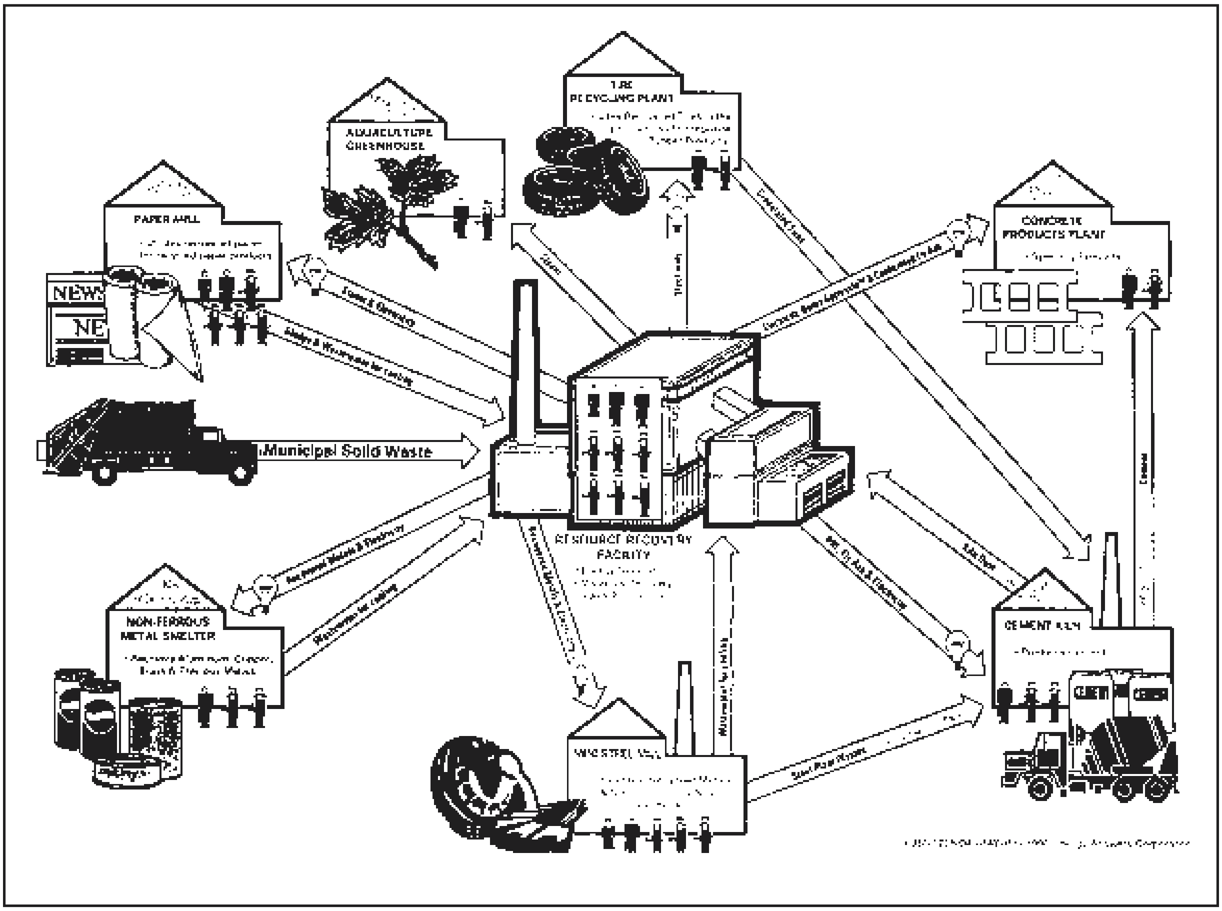
University of Hawaii. 1999. http://www.library.kcc.hawaii.edu

Welcome to Puerto Rico. 1999. http://www.welcome.topuertorico.org/reference/agri.html

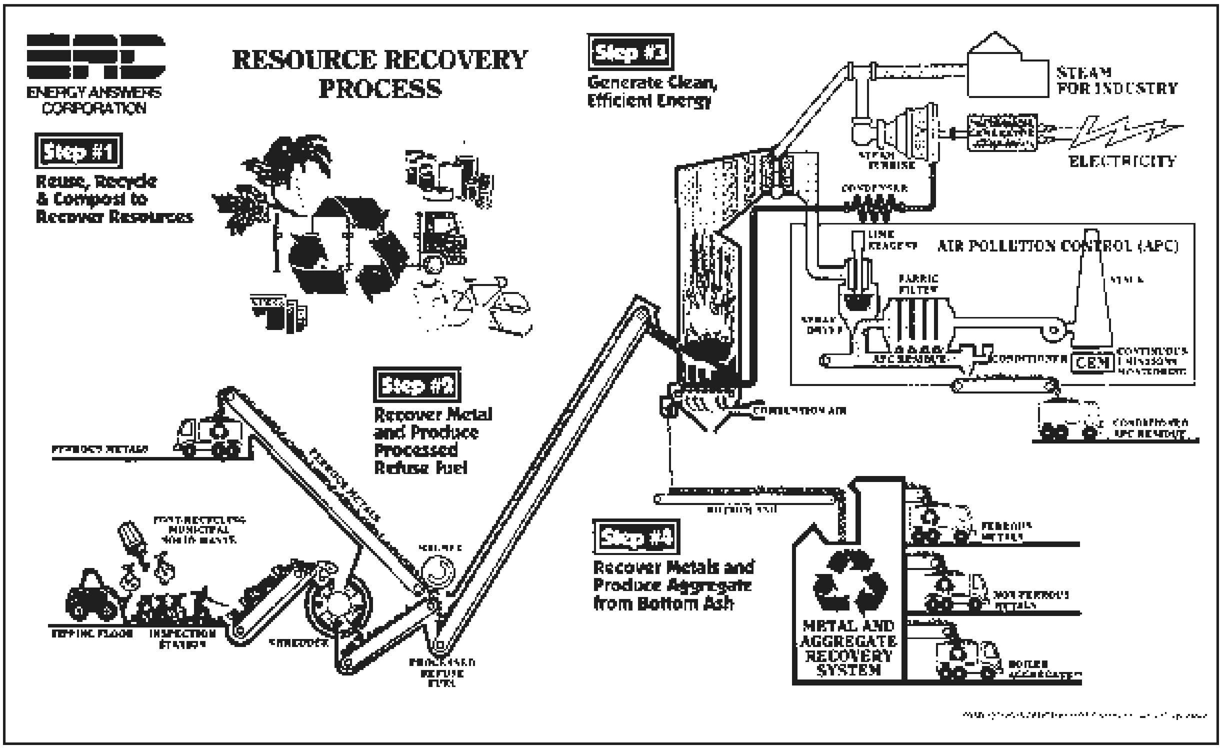
WEPA! Search Puerto Rico! 1999. http://www.wepa.com

Zero Emissions Research Initiative. 1998. http://www.zeri.org

APPENDIX A Integrated Industrial Resource Recovery Complex



APPENDIX B Resource Recovery Process



Part IV: The Urban Content–Studying New Haven

Efficacy of Industrial Symbiosis for Food Residues in the Greater New Haven Area 1998

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ABSTRACT
In this paper we explain how our group selected the food industry as the focus of our seed project and propose possible avenues for increasing the efficiency of the food industry in the New Haven area. We explore manufacturing facilities, distribution centers, small markets, large supermarkets, restaurants, and farms for their current inputs and outputs as well as projections of their future inputs and outputs. We conclude by proposing pollution prevention strategies for current practices, as well as potential improvements for the near and far future. We are hopeful that each of the suggestions made can be strategically implemented in the upcoming years. We feel that the success of a food industry project may help both to focus energy on and to attract more businesses to the concept of virtual eco-industrial parks.

INTRODUCTION

In 1997, the United States Environmental Protection Agency (EPA) announced the creation of a Sustainable Development Challenge Grant. The purpose of this grant was to promote industrial development in an environmentally responsible and economically sustainable manner. In response to the challenge, Marian Chertow, Director of the Industrial Environmental Management Program at the Yale School of Forestry & Environmental Studies, submitted a proposal for the New Haven Revitalization Project. The focus of the project was the creation of a "virtual" eco-industrial park in the greater New Haven area. As Chertow explained in the proposal:

> This project seeks to use the greater New Haven area to demonstrate a vital new concept to bring together economic growth and environmental innovation for the new purpose of urban revitalization. This concept begins with the belief that business interests and environmental interests are intrinsically tied to each other and simply need the right tools to accomplish common goals.

Using industries located in the greater New Haven region, the project planned to link companies that were using similar resources, through a complex materials exchange web. In essence, the project goal was the creation of a regional eco-industrial park in which the waste outputs of one company could be used as the input materials of another company.

The New Haven Revitalization Project proposal referred to two examples of eco-industrial parks – Kalundborg, Denmark and Brownsville, Texas. The first and most classic example of an eco-industrial park is the park located in Kalundborg, Denmark, a park that developed over many years as additional companies were drawn to the area. Each company maximized resource use and, through mutually beneficial collaboration with other park members, managed its wastes more effectively. The companies easily were able to share heat, water, and manufacturing by-products.

The Kalundborg example illustrates both the large length of time and amount of capital required for most eco-industrial parks to develop. Because much of the business in the New Haven area is already established and undeveloped land is limited, construction of new eco-industrial parks is unlikely. Therefore, Chertow envisioned the Revitalization Project as creating a virtual eco-industrial park (VEIP). In a virtual eco-industrial park, local businesses would be able to match their inputs and outputs with other regional facilities to maximize resource use. Exchanges between these facilities could include information, regulatory functions, marketing, waste, recovery, recycling, and substitution. She referred to the park in Brownsville, Texas as a model of a VEIP.

In a virtual eco-industrial park, local businesses would be able to match their inputs and outputs with other regional facilities to maximize resource use. Exchanges between these facilities could include information, regulatory functions, marketing, waste, recovery, recycling, and substitution.

The Brownsville Economic Development Council (BEDC), a broad-based community group comprised of 156 private businesses and public entities, promotes the economic and industrial development of the city of Brownsville, Texas. The BEDC is a joint partner with the city of Brownsville in the industrial symbiosis project, a plan initiated to enhance environmental sustainability along the Texas/Mexico border by creating a virtual eco-industrial park.

The Industrial Symbiosis project is currently in its second stage of development. The first stage was a preliminary feasibility study conducted in 1994 by the Research Triangle Institute under the support of the U.S. EPA. The study assessed the basic waste material flows in the Brownsville/Matamoros region, with specific focus on a few candidate industries.

While the results were positive, the early study did not lead to a developable project. First, members of solicited companies were often too busy to fully commit to participation. In addition, their input/output information was considered highly sensitive. Companies must report waste flow numbers to the government, and they fear legal retribution if their reported numbers do not coincide with actual flows. Furthermore, many companies were concerned with the issue of transporting the resources, and how they would report the wastes under the Resource Conservation and Recovery Act (RCRA).

While results were not immediate in the Brownsville VEIP, the concept of VEIPs remains intriguing due to the many potential benefits. Not only would participating companies be part of an exciting and innovative project, but collaboration with a VEIP would also:

- reduce pollution and environmental damage;
- reduce consumption of natural resources;
- allow the company to approach sustainable operations;
- invite process innovation;
- reduce raw material costs;
- reduce treatment and disposal costs.

Each of these benefits propels participating companies toward the ultimate goal of environmental sustainability. Unfortunately, most companies are unaware of the virtual eco-industrial park concept. The potential of VEIP projects is often unrealized unless the local business community is educated about the concept of industrial ecology.

Both Kalundborg, Denmark, and Brownsville, Texas provide strategies for the initiation of an eco-industrial park. For stationary EIPs, plants should have compatible waste streams and should be willing to relocate to the EIP site. For VEIPs, companies should be educated in sustainability and be willing to share data concerning their resource flows.

CHARACTERISTICS OF NEW HAVEN INDUSTRY

In 1995, the greater New Haven area supported a population of 502,420 citizens. Of that number, about half of the residents were regionally employed. The city maintained a 5.3% unemployment rate. In 1993, the majority of the labor force was employed in the services sector.

While the city of New Haven has lost much of its manufacturing business in the past several decades, as of 1993, 567 manufacturing businesses with over 20 employees were located in the greater New Haven area. Using the entire list

Table 1 New Haven Industries - Size and Percentage

Sector	# Businesses	# Employees	% of New Haven Employees in Sector
Construction	1,111	10,754	3.5
Manufacturing	567	66,300	21.3
Transportation and Utilities	NA	19,674	6.3
Wholesale Trade	1,614	19,029	6.1
Retail Trade	4,997	58,787	18.9
Finance, Insurance & Real Estate	NA	19,454	6.3
Services	6,362	116,858	37.6
Total	NA	310,856	100

NA: not available (Source: The Greater New Haven Chamber of Commerce 1998) of New Haven industries, the percentage of different manufacturing industries in the New Haven area was approximated. Based on rough calculations, it was determined that the metal industry maintains the largest number of companies in New Haven. The food industry was ranked second.

With an original focus on the metal industry, several metal manufacturers were contacted. Table 2 lists a selection of company information and general material flows for the metal industry.

Table 2 New Haven Metal Industries – Products and Wastes

Company	City	Product Description	Wastes Generated
Fluidyne Ansonia	Ansonia	Copper plumbing	Wood boxes, dirty cutting oil, metal scraps
Algonquin Industries	Guilford	Copper wire, A l and brass drawing scraps	Filtration cartridges, wooden pallets, metal
Sandvik Milford, Corp.	Branford	Bandsaw blades	Wooden pallets, steel strapping, scrap metal, oil

Each of the metal manufacturing companies listed above was able to account for its resource flows of scrap metal. The companies sent scrap metal back to their suppliers for monetary compensation, which was substantial and acted as an incentive for recycling. In addition, each of the three companies had installed sophisticated filters on their machinery to extract metal pieces from the lubricating oil. The company representatives felt that this effort enabled them to get the most out of their oil before it was collected and incinerated. They were not interested in using the oil in a material exchange. The biggest concern for these manufacturers was an overstock of wood pallets. Receiving the majority of their inputs on these wood pallets, these companies were forced to dispose of the high quality wood products as waste. Two of the companies even paid a wood chipper to dispose of the pallets. The other contact admitted to using the wood to build a shed in her backyard.

It should be noted that at least 15 metal companies were contacted, and only the three metal companies listed above were willing to comment on material flows. Possible factors in the reluctance of the other companies to comment on resource flows could be a fear of reporting large waste streams, lack of time, or a general feeling that they were efficiently using their materials. Like the companies contacted in the Brownsville project, the metal companies showed a general lack of understanding regarding the concept of eco-industrial parks.

After little success with these companies, it was concluded that the metal industry would not be useful as a seed project. The determining reasons for this were the following:

- There is a strong market for recycled metal. The companies were content to send the metal out of state to smelters who were able to return the metal to sheet, wire, and other commons forms.
- The companies felt they had effectively exhausted the life-span of the lubricating oil.
- Each company was generally not interested in participating in an eco-industrial park.
- The multitude of similar metal working businesses in the Greater New Haven area, creating similar products, makes material exchange quite difficult. To be effective as a seed project, it was felt that both a smelter and a refinery would need to be located in close proximity to New Haven; the city supports neither a smelting facility nor a refinery at present. Further, it can be assumed that locating either type of plant within the city boundaries would receive large amounts of resistance.

Based on these conclusions, our group turned to the food industry, the second largest industry in New Haven, comprised of the manufacturers, transporters, and sellers of fresh and processed foodstuffs. Participants in this sector range from supermarkets to hotels (see Table 3). The manufacturing list generated for New Haven County provided a company list for contacting industry members. Select companies contacted include: Hummel Brothers (producers of meat products), De Luca, Inc. (producers of pasta), Calabro (producers of cheese products), and Leon's (producers of baked goods). The names and descriptions of the other food sector types were retrieved from telephone books, reference materials, and general knowledge of the area.

The food industry creates an interesting case study because it is an area often neglected in the industrial ecology analysis of manufacturing efficiency. However, the waste streams from the food industry are substantial. While most

Table 3 Composition of the Greater New Haven Food Industry Sector

Type	Number	Representative Waste Flow	Total Waste Flow
Restaurants	613	50 kg	30,650 kg
Bakeries	111	20 kg	2,200 kg
Grocery Stores	365	25 kg	9,125 kg
Supermarkets	20	130 kg	2,600 kg
Universities	9	110 kg	990 kg
Hotels	21	40 kg	840 kg
Food Products	23	150 kg	3,450 kg
Total	1162	525 kg	49,855 kg

(Source: 1992 Census, personal interviews) studies focus on the chemical industry, the metal industry, and other big polluters, they miss the tremendous potential for materials conservation in the food industry. Waste streams from metal and chemical industries are complicated and considered to be private information. However, the food industry is familiar enough to everyone so that its residue streams are easy to visualize and comprehend and can be used as an example to educate the business community about environmental sustainability. In addition, this study could generate interest in the concept of virtual eco-industrial parks that could lead to greater industry participation.

Why Food?

The food industry produces large amounts of food for both local and global consumption. The industry also generates enormous volumes of waste. Although the food industry receives substantial attention for its often wasteful packaging materials and processes (e.g. the fast food sector), little is known about the rest of the food industry waste stream. Disposable food-service products (i.e. paper cups, bags, sandwich wraps) make up less than one-third of one percent of the volume of waste in current landfills. In comparison, in some foodservice processes up to twelve times more food is disposed of than packaging materials (Anderson 1993). Food, just as other solid waste, takes up landfill space and requires shipping to get to its final disposal destination.

Waste streams from metal and chemical industries are complicated and considered to be private information. However, the food industry is familiar enough to everyone so that its residue streams are easy to visualize and comprehend and can be used as an example to educate the business community about environmental sustainability.

Landfill space is shrinking, but generation of waste is not. As available landfill space decreases, tipping fees as well as transportation costs increase, since trash must be shipped farther. The National Restaurant Association states that three out of five restaurants report paying more for trash removal now than just a few years ago (FPI 1993). They also report that tipping fees have more than doubled since 1982. Therefore, the food industry is faced with two solid waste problems: an economic as well as an environmental one.

Food Flow Chart

Through data interpretation and research, the VEIP group was able to create a flow chart to map potential material flows throughout the food industry (Figure 1). It is an idealized scenario, realizable only with innovation and an extremely coordinated effort. As can be seen by following the various output lines, nearly all of the loops are closed:

- Waste water emitted by the food processor is recycled by the local Publicly Owned Treatment Works (POTW) and returned to the manufacturer for use as an input.
- Packaging materials are recycled by an outside firm and are returned to the processor in the form of recycled materials.
- Energy losses are captured to the highest degree possible and funneled back into industrial processes.
- Fats and oils are rendered by private firms and reused whenever possible by the food manufacturer.

- Air emissions are minimized; in the case of bakeries, where ethanol and methanol are released in large quantities, gaseous residues are captured and sent to the POTW where they are utilized in waste digesters.
- Salvageable (edible) scrap food is donated to regional food banks for local distribution.
- Non-salvageable food is sold to animal feed manufacturers and processed for animal consumption (cattle and swine can be viewed as inputs to some food manufacturers as raw materials).

Food manufacturers have been placed in the center of the diagram. These include not only large and small food processors (food industries), but restaurants, hotels, universities, and, for the purposes of our analysis, large and small groceries. The bulleted points listed in the box are the generic processes of food manufacturing.

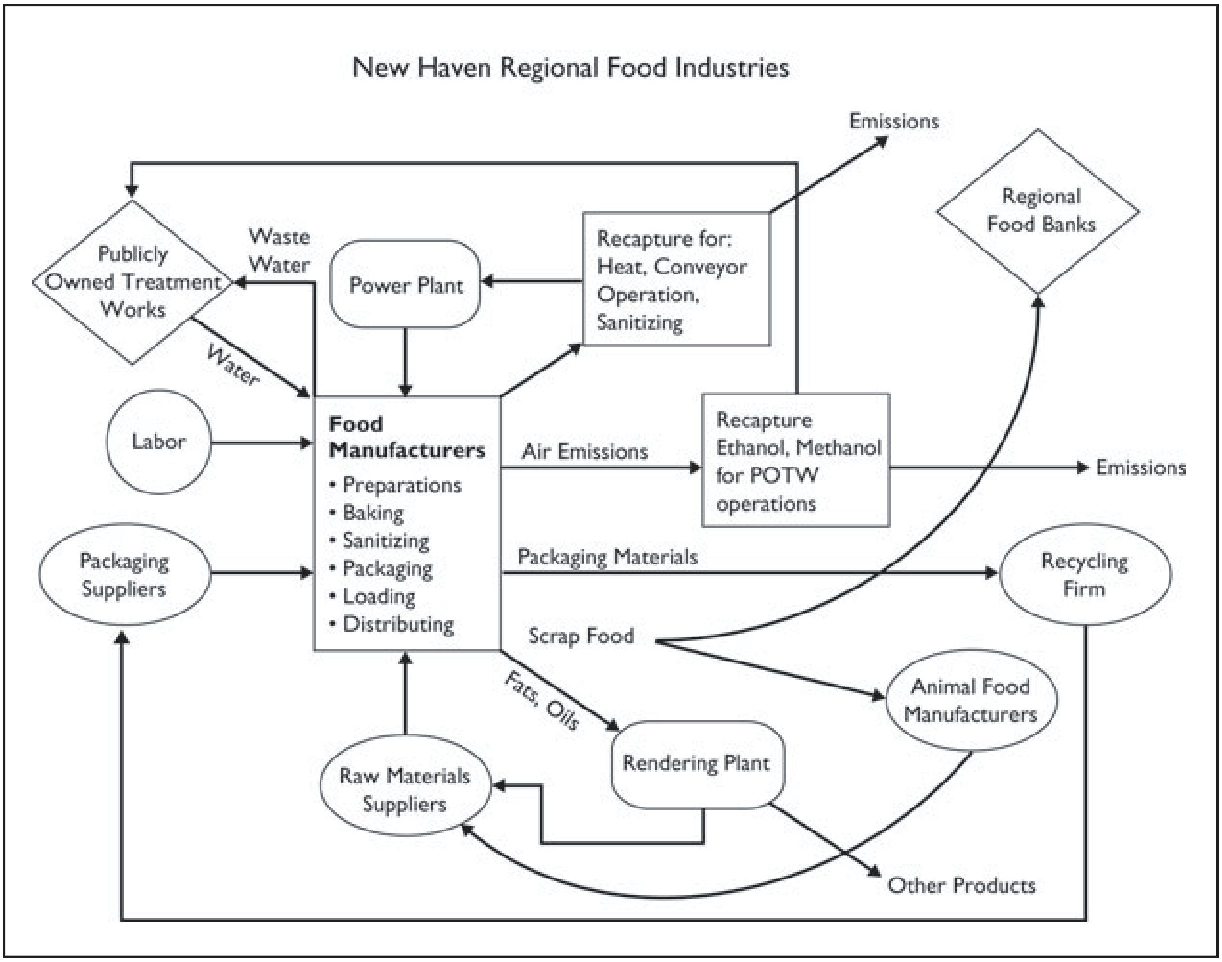

Figure 1 Food Industry Material Flows

Inputs to the food manufacturing process include:

- Energy – for heat, cooking, conveyor operation, sanitation processes, gasoline distribution, and general lighting and heating of the facility;
- Water;
- Packaging Materials – both from suppliers to be used for packaging end products, and from packaging from raw materials suppliers;
- Raw Materials – flour, meats, spices, fats, oils, vegetables, fruit, dairy products, eggs, etc.;
- Labor.

Outputs include:

- Energy – residual heat from many of the processes described above;
- Air emissions – including ethanol and significant amounts of volatile organic compounds for some producers;
- Packaging materials – generally from raw materials suppliers;
- Scrap food – both salvageable and non-salvageable;
- Fats, oils;
- Wastewater.

NEW HAVEN FOOD SECTOR

Small Groceries

New Haven is a town replete with small grocery stores, one of the city's greatest charms. Small neighborhood groceries often provide not only staple foods, but gourmet and specialty items as well. Additionally, the local grocery provides a place for neighbors and friends to interact, and to find out about community events. In New Haven, residents get to know their local grocers by name, and they will often develop a strong sense of loyalty to their favorite grocery.

For each sector of the food industry, we will list the corresponding inputs and outputs to introduce possible means to improve the flows.

Most neighborhood groceries in New Haven attempt to project an image of social and environmental responsibility, and this directly influences what they do with their garbage. For the most part, any packaging material, especially corrugated cardboard boxes, is appropriately recycled. Salvageable food items – food which can no longer be sold, but which may still be eaten – are often donated to local food banks or homeless shelters.

Inputs

- Produce items
- Dairy products
- Fresh meats
- Canned goods
- Packaged goods
- Corrugated cardboard boxes

Outputs

- Spoiled food
- Salvageable food products
- Corrugated cardboard boxes
- Other packaging materials

Present

The relationships between residents and neighborhood groceries can help to create more innovative, informal, and environmentally-friendly solutions for the disposal of food wastes. Most neighborhood groceries in New Haven attempt to project an image of social and environmental responsibility, and this directly influences what they do with their garbage. For the most part, any packaging material, especially corrugated cardboard boxes, is appropriately recycled. Salvageable food items – food which can no longer be sold, but which may still be eaten – are often donated to local food banks or homeless shelters. At least one New Haven grocer has established procedures for donating salvageable food to Rachel's Table, a New Haven food bank. Although most spoiled food and produce trimmings are discarded, some groceries have informal arrangements with their neighbors, who take this food away to be composted and used in their backyard gardens.

Near Future

As discussed above, the two major output flows for groceries are packaging materials and waste food. In the near future, we see several possibilities for reducing or eliminating these flows:

- First, continued and improved recycling would serve to greatly minimize the amount of garbage discarded. Additionally, if recycling were performed by a private firm, the grocery could receive a small amount of extra revenue.
- Second, informal composting arrangements with neighbors could be formalized and expanded, since only a small portion of waste food and trimmings is currently utilized through the informal process. We recommend establishing a public, or even a private composting service (perhaps managed by the Connecticut Agricultural Extension) which would collect non-salvageable food from New Haven groceries and compost these materials. This would take advantage of the large economies of scale associated with composting and produce a high-quality fertilizer that could be sold to residents, or donated to community gardens. It should be noted that there may be large transportation impacts associated with the collection of the food scrap.
- Finally, any salvageable food should continue to be donated to local food banks and shelters.

Long-Term

In the long term, neighborhood groceries may look to their suppliers to reduce waste flows. Especially where groceries have long-standing and comfortable relationships with their suppliers, it may be possible for them to demand that products be packaged in recycled and recyclable materials. Alternatively, a take-back arrangement could be made with suppliers so that the supplier agrees to "take back" and recycle or reuse whatever packaging materials or food wastes cannot be easily recycled by the grocer. Source reduction practices, such as requiring that suppliers transport goods in bulk rather than in individually wrapped packages or containers, can also contribute to waste reduction and elimination goals.

Food Industries

Food industries, or processors, are those companies that manufacture packaged or processed food stuffs. Examples from New Haven include Hummel Bros., Inc., De Luca Pasta, Lender's Bagels, Inc., and Peter Paul Candy, Inc. Several food producers in the New Haven area were contacted and interviewed about the content and use of their residues. Mechanisms for discarding food waste differed based on the size and longevity of the company.

Inputs

- Grains
- Meats
- Spices
- Flour
- Sugar
- Fats
- Oils
- Packaging materials

Outputs

- Used packaging materials
- Scrap food
- Fats, oils

Present

Larger companies tend to be more adept at reducing the amount of waste discarded into the municipal solid waste stream. Some of the larger companies have established arrangements with a New York-based broker that collects food scraps and sells them to a company that scientifically formulates cattle feed. Other companies sell their scraps or meat trimmings to Connecticut pig farmers. This seems to be a fairly common practice across the entire food industry. There are also some companies that have arrangements with private fat rendering firms.

Common wood and paper-based packaging materials are recycled to a significant extent. Corrugated cardboard, in particular, is very economical to recycle and is recycled by the vast majority of food industry firms. The largest firms operate pallet exchange programs with their suppliers, so that the supplier backhauls as many wood pallets as are delivered. Non-recyclable or difficult to recycle packaging materials are disposed of in the trash. Motivated strictly by economics, larger firms are extremely efficient at recycling and reusing their waste flows.

Smaller companies we interviewed are not quite as successful at reducing their waste disposal. These companies did not have arrangements with private rendering companies or pig farmers, nor did they have arrangements with private recyclers. If waste is municipally recycled, it may be separated from other rubbish. For the most part, though, if what comes into the firm does not go out as a product, it is discarded.

Near Term

In the near term, efforts should focus on reducing the waste flows from smaller firms. Even though the waste flows from small firms are significantly smaller than those of larger firms (tens of kilograms daily as opposed to hundreds), a much greater proportion of their waste is discarded in the municipal solid waste stream. We suggest utilizing the formal composting service (as established under the near-term groceries recommendations) to collect and compost non-salvageable produce and produce trimmings. Also, like the small groceries, donations of salvageable food to food banks could be encouraged, particularly if tax benefits accompanied this act of good will. Finally, there may be a financial incentive for small food manufacturers to sell their scrap meats or other foods to regional swine farmers. The barrier here is probably one of information. No small firm we contacted had even considered the possibility of selling its wastes to pig farmers.

Packaging wastes could best be addressed in the short term by expanding municipal collection and recycling programs. Current recycling programs leave out a good deal of recyclable materials. In the near term, municipal recycling programs could be expanded to include a larger variety of products and materials.

Long Term

In the long term, the leaks that occur in the larger companies' flows should receive special attention. First, recycling of packaging materials should be made as efficient as possible. This means finding a way to recycle or reuse packaging materials, or finding a different, more easily recyclable packaging material altogether. Second, larger food manufacturers should begin to address air and water emissions. Amounts and impacts of these emissions should be quantified, and means to reduce them identified.

Large food manufacturers might also consider establishing pollution prevention programs, or instituting take-back schemes with their suppliers and distributors. Indeed, a food manufacturer might become an environmental leader in the industry by promising to take back and recycle or reuse any packaging, shipping materials, and other non-sellable items which accompany the product. Better yet, a food manufacturer could guarantee distributors that it will take back and compost whatever portion of its products cannot be sold.

…a food manufacturer might become an environmental leader in the industry by promising to take back and recycle or reuse any packaging, shipping materials, and other non-sellable items which accompany the product. Better yet, a food manufacturer could guarantee distributors that it will take back and compost whatever portion of its products cannot be sold.

In the current scheme, almost all of the food waste is recycled or reused. As in the case of Peter Paul Candy, waste is transported to a food broker in New York state, and from there it is shipped to cattle feed manufacturers. However, the transportation impacts here can be quite large, and may offset the environmental benefits gained from reusing the waste. In a more efficient system, one designed after the eco-industrial park model, the cattle feed manufacturer would relocate near Peter Paul Candy and establish a direct, mutually beneficial relationship with Peter Paul. Not only would transportation impacts be reduced, but both companies also would benefit by removing the middle man from the equation.

Similar arrangements could be made with other food manufacturers depending on the type of non-product outputs produced. For example, a local meat processing firm might provide ideal inputs to a pet food manufacturer. Like the proposed relationship between Peter Paul and the cattle feed producer, this hypothetical link would be mutually beneficial. It would provide additional revenue for the meat processor, an inexpensive input for the pet food manufacturer, and environmental benefits to both companies. Although NIMBYism (Not In My Back Yard) might preclude the introduction of this type of manufacturer, the prospects may be better in New Haven than in other communities. In fact, New Haven might even welcome the additional industry, especially given the recent loss of industry the town has experienced.

For smaller firms, the first step in the long term is to employ, at least part-time, an environmental manager. Many of the firms we spoke with expressed a need for someone to deal with their waste flow and other environmental issues. Employing a person with expertise in environmental management would allow smaller firms to apply the same degree of environmental sophistication as the larger firms. This might include the possibility of expanded and enhanced recycling programs, and more efficient ways to reuse waste products and waste packaging materials. Further, smaller firms might institute take-back schemes similar to the ones utilized by larger firms.

For smaller firms, the first step in the long term is to employ, at least part-time, an environmental manager. Many of the firms we spoke with expressed a need for someone to deal with their waste flow and other environmental issues.

Restaurants

There are hundreds of eating and drinking establishments in the New Haven area. Indeed, eating and drinking establishments account for over 10% of the total retail sales in greater New Haven (GNHCC 1998). The industry's significant contribution to the municipal waste stream could be reduced by further environmental and waste flow analyses.

Inputs

- Manufactured food products
- Spices
- Meats
- Raw materials (flour, sugar, milk, butter)
- Fruits, vegetables
- Breads

Outputs
- Discarded packaging
- Non-salvageable scrap food
- Salvageable food
- Waste water

Present
Currently, most restaurants discard the vast majority of their wastes into the municipal solid waste stream. Although refundable corrugated cardboard boxes, aluminum, and glass containers are generally recycled, non-refundable containers and packaging, as well as waste food-both salvageable and non-salvageable-are usually tossed in the dumpster. One restaurant we contacted that serves over 250 customers daily also discards an average of 50 kilograms of waste into the municipal garbage per day.

Near Term
In the near term, eating and drinking establishments in the New Haven area can address a significant portion of their waste flows. First, restaurants can greatly expand their recycling practices. Many of the containers discarded by restaurants today are made of recyclable materials-plastic, tin, etc. However, because these are non-refundable containers, restaurants have little incentive to recycle them. This situation could change if restaurants recognized that recycling these items through private recycling firms can produce enough revenue to warrant the extra labor involved in separating these items from other refuse and transporting them to a recycling center.

Second, food scraps, which constitute the largest portion of a restaurant's waste stream, also should be recycled or re-used. Like other food sector industries, the restaurant industry produces a significant amount of salvageable food scraps, which should be donated to regional food banks. Non-salvageable food scraps and vegetable trimmings could be collected and composted as part of the regional composting service.

…the larger problem underlying food waste is a result of the unnecessarily large portions served at many eating and drinking establishments, a tendency that results in a good deal of scrap food being left on the plate after the diner has finished eating. A more radical, long-term policy might address this issue and institute an industry-wide reduction in serving sizes.

Long Term
In the long term, drinking and eating establishments have the potential to form environmental coalitions and together demand that suppliers provide food and raw materials in packaging which has a minimal percentage of recycled content and which is easily recyclable. Near term policies would address most of the less difficult problems associated with food waste flows. However, the larger problem underlying food waste is a result of the unnecessarily large portions served at many eating and drinking establishments, a tendency that results in a good deal of scrap food being left on the plate after the diner has finished eating. A more radical, long-term policy might address this issue and institute an industry-wide reduction in serving sizes.

Hotels

There are several large hotels located in New Haven, and with the Omni Hotel recently opening its doors, this service industry is ripe for examination. Although hotels aren't generally thought of as part of the food sector, they are an important contributor in that they operate like a large restaurant.

Inputs

- Manufactured food products
- Spices
- Meats
- Raw materials (flour, sugar, milk, butter)
- Fruits, vegetables
- Breads

Outputs

- Discarded packaging
- Non-salvageable scrap food
- Salvageable food

Present

In the present arrangement, hotels recycle refundable glass, plastic and aluminum containers, as well as corrugated cardboard boxes. Like other industries, the hotel industry generally discards any materials that are not easily recyclable. This includes food wastes as well. However, one hotel that we contacted has an informal arrangement with Rachel's Table, the first and largest food bank in New Haven. In this special situation, the hotel's Chief Financial Officer also sits on the board of Rachel's Table, and he encourages the hotel to donate scrap foods to the organization whenever there is a large function or event.

Like other industries, the hotel industry generally discards any materials that are not easily recyclable. This includes food wastes as well. However, one hotel that we contacted has an informal arrangement with Rachel's Table, the first and largest food bank in New Haven.

Near Term

Like the other industries discussed, in the hotel industry opportunity exists to expand the recycling of waste packaging materials. Furthermore, the hotel industry could follow the lead of restaurants and other food sector industries and formalize its arrangement with Rachel's Table. Rather than restricting donations just after large events, all salvageable food wastes could be donated. Non-salvageable food wastes could easily be added to the proposed scheme of a community composting service.

Long Term

In the long term, the hotel industry might use its size to influence suppliers and encourage them to deliver products in minimal, recycled, and easily recyclable packaging. For salvageable food products, hotels might cut out the middleman (local food banks) and provide meals to the homeless and needy as a service to the New Haven community. One could imagine that a hotel could offer a weekly or bi-weekly meal to New Haven's indigent. This could be done during non-regular hours, or in a separate facility so that paying customers would not be disturbed while eating. Further, if such a service were coordinated with other hotels in the region, the industry as a whole could provide a week's worth of meals to some portion of the area's needy.

Universities

In the New Haven area, there are nine universities/higher learning institutions. While some are commuter schools, which do not provide food service for an on-campus student population, several do. In particular, Yale University provides meals to over 8,000 graduate and undergraduate students, and to a significant portion of the University's faculty and staff. There are nearly twenty dining halls on the Yale campus to serve this population of approximately 10,000 people.

Inputs

- Manufactured food products
- Spices
- Meats
- Raw materials (flour, sugar, milk, butter)
- Fruits, vegetables
- Breads

Outputs

- Discarded packaging
- Non-salvageable scrap food
- Salvageable food
- Soiled paper products

Present

The professional schools' dining halls (including the Law School, Hall of Graduate Studies, Divinity School, Kline Biology Tower, School of Management, and School of Art & Architecture) are very different from other Yale services. Our contact at the School of Management dining hall stated that his job is to ensure that very little food is discarded. Because most of the items available at the professional school dining halls are made to order, there is little in the way of leftover food that needs to be discarded. Any produce or other salvageable items are re-worked by the head chef into the meals for the next day. Other items that cannot readily be used are donated to Rachel's Table.

However, a good deal of scrap food (mostly table scraps) is discarded. For health reasons, this food can obviously not be re-used or donated, and must therefore be discarded with other rubbish. Additionally, packaging wastes which cannot easily be recycled (i.e., non-refundable plastic or metal containers, plastic wrapping, etc.) are usually discarded.

The most important dining hall on the Yale Campus, in terms of waste minimization and output reuse, is the Commons. The largest of the Yale Dining

Halls, the Commons produces roughly one barrel of food scrapings and trimmings per week, and approximately three dumpsters of soiled paper products (such as used napkins, non-corrugated boxes, and wax paper) per week. All salvageable foods from the Commons are donated to area food pantries, such as Rachel's Table. The collected food scrapings and trimmings are picked up weekly by a local pig farmer to use for feed. Alternatively, all dumpsters of non-recyclable paper items are eventually disposed of in area landfills. The Commons does follow University recycling guidelines and regularly recycles aluminum, glass bottles, white office paper, newspaper, and corrugated cardboard.

Near Term

Using the Commons as an example of all university dining halls, the greatest areas for improvement lie in the minimization of soiled paper products. One solution to this problem (which is now being explored by dining services) is the use of paper pulpers in dish rooms. This would allow paper-based products to be separated and shredded (along with any food scraps that may go with them), thus significantly diminishing their volume. The resultant waste is either landfilled or sold to cattle farmers as feed (the paper serves as roughage).

Another area of improvement could be the distribution of food scrapings to area swine farmers. At one time all of the dining halls at Yale gave their scrapings and trimmings to area pig farmers. This practice has ended at all of the dining halls except for the Commons due to a drastic decrease in area pig farmers over the last 25 years. Additionally, other alternatives such as area composting initiatives should be examined.

We recommend that the university try to work with student and area NGOs in order to standardize possible area composting and recycling systems. Such a maneuver would have the doubly beneficial effect of improving the university's public image, and promoting social consciousness within the student body.

Long Term

While near term proposals theoretically will repair most of the leaks in the university's waste flow, some innovative long-term strategies might be implemented both to secure the viability of near term repairs, and to prevent waste from originating. We recommend that the university try to work with student and area NGOs in order to standardize possible area composting and recycling systems. Such a maneuver would have the doubly beneficial effect of improving the university's public image, and promoting social consciousness within the student body. Incidentally, the strategy would also lower the university's waste disposal costs, reduce the amount of waste being hauled to the landfill or incinerator, and provide quality compost for community parks and gardens.

We also propose that the university implement take-back programs with its suppliers, requiring them to supply goods in minimal recycled and easily recyclable packaging. Additionally, the university could continue to reduce many of its paper, table, and plasticware disposal problems by increasing the use of ceramic dishes and metal utensils. A full life-cycle analysis could determine which is the most environmentally responsible balance between the use of paper/plastic and ceramic/metal.

Supermarkets

Large- to medium-sized retail food stores (or supermarkets) are the primary centers for food distribution in the United States. Often associated with national chains, supermarkets provide a large selection of processed and packaged foodstuffs, as well as fresh foods of all varieties. Along with processed and packaged foodstuffs, many supermarkets offer services ranging from full service bakeries to fresh fish markets. Due to the large size of supermarkets, their large amounts of material flows, and their relative importance to surrounding communities, supermarkets are obvious areas of study when determining, and hopefully closing, the life-cycle loops of the food industry in any populated area.

Inputs

- Fresh produce
- Fresh meats (including seafood)
- Fresh cheese and other dairy foods
- Fresh material foodstuffs for in house processing (i.e., flour, eggs, milk for bread)
- Processed or canned food (including the immediate packaging that the food comes in)
- Packing material for fresh produce and meat (fresh produce is packed in standard cardboard boxes, meat/seafood is packed in wax-lined cardboard boxes)
- Plastic and wood pallets for material movement and storage
- Styrofoam and plastic coating (i.e., Saran Wrap) for the packaging and display of fresh produce and meat/seafood.

Outputs

- Trimmings from produce
- Trimmings from meat and seafood
- Corrugated cardboard
- Corrugated cardboard with wax
- Wood pallets
- Styrofoam
- Solid fresh food waste (past freshness)
- Solid packaged waste

Present

Currently, the waste (output) stream from Super Stop & Shop (our example) is disposed of in a variety of ways. Produce which is no longer considered to be fresh is wrapped in plastic coating with a Styrofoam backing and sold at a discounted price. All discounted produce that is not sold after a given time is discarded (along with the plastic and Styrofoam backing) in a waste dumpster. All produce trimmings (discolored, non-fresh, or inedible parts of produce that is removed before it is put on display) are immediately discarded in a standard waste dumpster. No effort is made to separate this material, and no alternative methods of disposal have been identified.

Meat and fish trimmings are separated from the solid waste trash stream and stored. These trimmings are routinely recovered by a private meat rendering firm. Exact uses for the rendered meat is not known, but assumptions can be made that it is used in wax manufacturing, cosmetic supplies and meat-based pet food. All unused or damaged dry/canned foodstuffs, as well as bakery foodstuffs, are handled in one of two ways: 1) food is delivered directly to local food banks where it is dispersed to local food shelters, soup kitchens, or other social programs as donations, or 2) salvageable food is sent back to food distribution centers. If the food that is returned to a distribution center is in a large enough bulk, a representative from the foodstuff producer will give the supermarket a credit on the unused goods. These goods are then donated to local food banks.

Exact uses for the rendered meat is not known, but assumptions can be made that it is used in wax manufacturing, cosmetic supplies and meat-based pet food.

Packaging materials constitute a very significant waste flow for supermarkets, and are dealt with systematically. All pallets are returned to suppliers in a formalized take-back arrangement. Transporters are required to take back the same number of pallets they deliver, thus reducing the need for the manufacturing of new pallets, and preventing their disposal into landfills or incinerators. Super Stop & Shop takes this idea one step further; instead of using wood pallets for internal delivery (delivery from store to store or distribution center to store), the Super Stop & Shop chain owns its own plastic pallets. These pallets are collected and reused within the company, reducing the stock of pallets and virtually eliminating the need to use virgin materials in the creation of new pallets.

All corrugated cardboard used for shipping is compressed and prepared for recycling, which is picked up roughly three times a week. This cardboard is sold to a private company for profit. All wax coated cardboard used for shipping meats, poultry, and fish is discarded into a standard waste dumpster. This is because there is no economically feasible means for recycling.

In sum, it can be estimated that roughly one standard-size dumpster of waste is disposed of each week (approximately 900 kilograms). By extrapolation, it can be estimated that roughly three to three and one half dumpsters of cardboard are prepared for recycling per week (2,700 - 3,100 kilograms).

While Super Stop & Shop is a relatively large source of waste output, most waste streams have already been closed through simple business evolution. The entire waste management system is self-sustainable, with dumping costs covered by the profit made in cardboard recycling. However, like most systems, improvements can always be made.

Near Term

In the immediate future, a number of recommendations could be made on a sector-wide basis. The first, and relatively easiest to implement, would be to create a system of separation for produce trimmings. These trimmings could be used for livestock feed (such as pigs) or for composting. It would be necessary to explore the possible transportation infrastructure that exists in order to determine the economic feasibility of collection. On a local basis, however, it could be possible to sell trimmings to local farm collectives or neighborhood composting initiatives.

In the near future, the most important sustainable practice that is currently in use and could be expanded is the use of plastic pallets. Due to the size of the supermarket chains, it may be possible for them to demand the use and reuse of plastic pallets from all their suppliers. This would drastically reduce the use of virgin wood material, and lower pallet stocks.

Long Term

In the far future, the most important changes that could be made in the supermarket sector would be to explore and expand the use of tax incentives in the donation of foodstuffs. It may be possible on a local or state level to give tax breaks to those sectors that can find sustainable uses for food waste. This would include processed food donations to redemption and food centers, as well as solid and liquid food wastes to area farmers. These tax breaks would provide an economic incentive to find more sustainable uses for food waste. Additionally, to increase the importance of local food banks such as New Haven's Rachel's Table, local and state governmental agencies could provide funding to the banks, not for their role as charities, but for their role as municipal waste recyclers. In collecting salvageable food wastes from supermarkets and other food manufacturers, food banks not only provide a service to the needy, but also divert large volumes of waste from municipal landfills and incinerators, an often overlooked contribution to society.

It may be possible on a local or state level to give tax breaks to those sectors that can find sustainable uses for food waste. This would include processed food donations to redemption and food centers, as well as solid and liquid food wastes to area farmers.

ATTRACTING NEW VEIP PARTICIPANTS

While the implementation of VEIP practices among industries currently situated in the New Haven area is important, one of the most critical factors in implementing a VEIP within the food sector is to attract new participants. Other factors include practical design issues, priority setting, and financing concerns. In order for a Greater New Haven Virtual Eco-Industrial Park to become a working model, it is necessary to recognize and address potential barriers early in the project's creation. To address these potential problems, the following recommendations are made:

1. Work with existing political and economic systems. In order to overcome the majority of the problems presented, it is necessary to lessen the fears and the risks to potential investors. This can be done a number of ways, including securing national, state, and local funding in order to leverage further capital; using industrial and professional associations as a monetary and information resource; using universities for technical, research, and development assistance; and looking to NGOs for community support (Resources for Sustainability Efforts 1997). In the New Haven area, two possible resources for the future implementation of the VEIP program are the Office of Business Development's Business Retention and Expansion Program, and the Technology Investment Fund, Inc. Working to attract new businesses to New Haven and to expand existing ones, the Business Retention and Expansion Program provides a variety of loans, site, and technical assistance in order to facilitate industry relocation and strengthen the city's economic base (New Haven Online 1999). The Technology Investment Fund, Inc. is a non-profit corporation that provides near-equity venture financing to early stage, technology based businesses (New Haven Online 1999). These are two avenues that could be explored as economic incentives not only for food-based industries, but for all incoming industries.

2. Educate potential industries. As stated previously, one of the largest barriers to the implementation of this project is the apprehension felt by potential participants and investors. An aggressive educational program, including media services, would be extremely helpful in reducing this apprehension.

3. Locate, map, and present potential brownfield sites in the New Haven Region. The presentation of area brownfield sites as development locations could interest potential participants. Knowing that an area is free from certain liabilities, and has the surrounding infrastructure to support a medium- to large-sized industry, is sometimes enough to encourage new industries and economic growth. By presenting possible development sites as a facet of the VEIP program, the brownfield initiatives could serve as a mechanism for project implementation.

4. Locate and promote model companies. In order for the VEIP project to work, it will be necessary to find and promote model industries to "start the ball rolling." Few industries want to start a relocation and resource management program in an area of which they have little knowledge. The greatest example of a VEIP project would be a working symbiosis between just two companies, which would present a working model to which prospective participants can refer.

RECOMMENDATIONS FOR NEW VEIP PARTICIPANTS

We offer two specific recommendations for participants that would benefit from relocation to New Haven: rendering plants and processed animal food industries.

Rendering plants

Rendering plants use byproducts from meat and poultry processing to produce tallow, grease, and protein meals. Many operate in conjunction with meat processing plants, while others operate independently by collecting food from a variety of sources. Rendering can produce edible fats, fat for livestock, soap production, and fatty-acid manufacture. The fat comes out in many grades depending on the input and the quality of the manufacturing process. Because rendering plants do produce odor and emissions, they need to maintain air quality control systems.

Dog/Cat Food Industry

In exploring the many possible receivers of food waste input, an exciting possibility is the pet products industry. While most dry dog/cat food is grain-based, much of the moist food contains meat and meat byproducts. By definition (as provided by Heinz Pet Products, the second largest producer of dog and cat food in the United States), meat byproducts encompass all "non-meat" parts of food-source animals. This includes organs, spleens, kidneys, livers, bones, blood, fatty tissue, and intestinal systems. Most of this material is purchased by suppliers of rendered meat products.

Because of its dependence on the meat-rendering sector, the dog/cat food industry is an interesting sector to examine. As explored earlier in this paper, meat rendering industries can be seen as one of the primary receivers of animal trimmings and waste. If it were possible to entice one of these industries to the New Haven Area, it might also be possible to entice pet product manufacturers.

…meat byproducts encompass all "non-meat" parts of food-source animals. This includes organs, spleens, kidneys, livers, bones, blood, fatty tissue, and intestinal systems.

LIFE CYCLE ASSESSMENT OF FOOD PRODUCTS AND PRODUCTION SYSTEMS

Life Cycle Assessments (LCA), methods of analyzing and assessing the environmental impacts caused by a product from 'cradle to grave,' have proven to be extremely beneficial in the transformation of products and processes toward a more sustainable future (Anderson 1993). In reviewing food production systems, LCAs are becoming essential in the acquisition of product information, and have helped in prioritizing the environmental loadings in the various treatments of food and food waste.

Several Life Cycle Assessments dealing strictly with the food sector have been produced. The Swedish Waste Research Council has documented a number of LCA reports of food products and production systems ranging from measures of eco-balances for the canning industry to a study of the packaging and life cycle of margarine. While the studies were not directly targeted at correcting or improving production systems, certain assumptions regarding environmental applications were made in this regard:

1. The influence of different packaging and preservation methods. According to a study by J.M. Kooijman, the most waste in food production is associated with fresh produce (Anderson 1993). Importing produce causes "a steep rise in the use of energy and the energy consumption" that can "surpass any method of packaging" (Anderson 1993). Simply stated, much of the waste in a food system arises from food which spoils or goes bad during shipment. More effective shipment methods, better shipping technology, and an efficient determination of actual product use in certain areas (to avoid shipping too much) would probably have a large impact on minimizing energy and food waste.

2. One-time versus reuse of packages. While much work has been done in comparing one-time (non-recyclable) packages with returnable or recyclable packages, little has been done to study the behavior of consumers (Anderson 1993). Food waste can be minimized by determining the demand scale of consumers and fashioning food packaging and availability to this demand.

3. Matching supply and demand. By determining the actual amounts consumers desire, the food industry can better tailor what foods should be produced.

The use of LCAs in the New Haven Revitalization Project would give a concrete foundation to future environmental development of regional food industries and services. Through these assessments, we can not only determine the inputs and outputs in our system, but we can also determine the areas that need specific concentration for improvement.

MATRICES FOR THREE SCENARIOS

Combining each of the food businesses into present, near, and far future perspectives, and using an extremely basic LCA framework, the following three matrices were constructed to analyze the environmental impacts of the food industry:

Scenario 1: Present Situation

- Informal composting (some groceries)
- Some food given to shelters
- Little public information
- Lots of trash
- No concerted efforts
- No system

Table 4 Matrix for Present Situation

Life Stage	Materials Choice	Energy Use	Solid Residues	Liquid Residues	Gaseous Residues	TOTAL
Pre-Manufacture	2.0	2.5	2.0	3.5	2.5	12.5/20
Product Manufacture	3.5	3.0	3.5	3.5	3.5	17/20
Product Packaging	1.5	3.0	1.5	3.5	3.5	13/20
Product Use	4.0	3.5	3.5	4.0	4.0	19/20
Recycling Disposal	1.0	3.0	2.5	3.0	3.0	12.5/20
TOTAL	12/20	15/20	13/20	17.5/20	16.5/20	74/100

Explanation of Scenario 1 Matrix:

PRE-MANUFACTURE	
Materials choice	2.0 (Recycled materials not used, some pesticides included)
Energy use	2.5 (Substantial energy use in transport)
Solid residues	2.0 (Little attempt to minimize packaging or reuse packaging materials)
Liquid residues	3.5 (Only minimal residue produced)
Gaseous residues	2.5 (Substantial emissions from transport)
PRODUCT MANUFACTURE	
Materials choice	3.5 (Some pesticide included)
Energy use	3.0 (Some energy use)
Solid residues	3.5 (Some residue produced)
Liquid residues	3.5 (Some residue produced)
Gaseous residues	3.5 (Cooking gas produced)
PRODUCT PACKING AND TRANSPORT	
Materials choice	1.5 (Various materials used, but no effort to reduce materials)
Energy use	3.0 (Some energy use in transport Solid residues
Solid residues	1.5 (No recycling instructions, some packing not recycled)
Liquid residues	3.5 (Only minimal residue produced)
Gaseous residues	3.5 (Only minimal residue produced)
PRODUCT USE	
Materials choice	4.0 (No concerns)
Energy use	3.5 (Only minimal residue produced)
Solid residues	3.5 (Only minimal residue produced)
Liquid residues	4.0 (No residue produced)
Gaseous residues	4.0 (No residue produced)
RECYCLING AND DISPOSAL	
Materials choice	1.0 (Various wastes thrown away)
Energy use	3.0 (Some energy use in disposal)
Solid residues	2.5 (Most wastes are solid residues)
Liquid residues	3.0 (Some water used in washing dishes and utensils)
Gaseous residues	3.0 (Some residue produced in transport)

Scenario 2: Near Future Situation (5 years later)

- Formalized composting
- Food bank system
- Increased food use
- Increased public information

Table 5 Matrix for Near Future Scenario

Life Stage	Materials Choice	Energy Use	Solid Residues	Liquid Residues	Gaseous Residues	TOTAL
Pre-Manufacture	2.0	2.5	2.0	3.5	2.5	12.5/20
Product Manufacture	3.5	3.0	3.5	3.5	3.5	17/20
Product Packaging	1.5	3.0	1.5	3.5	3.5	13/20
Product Use	4.0	3.5	3.9	4.0	3.9	19.3/20
Recycling Disposal	3.5	3.5	3.5	3.0	3.0	16.5/20
Total	14.5/20	15.5/20	14.4/20	17.5/20	16.4/20	78.3/100

Generalizations:

- Pre-manufacture, product manufacture, and product packaging have not been changed much in terms of environmental concern in the short run.
- However, there are changes in product use, and recycling and disposal.

Explanation of Scenario 2 Matrix:

PRODUCT USE	
Materials choice	4.0 (No concerns)
Energy use	3.5 (Only minimal energy use)
Solid residues	3.9 (Very little residue produced)
Liquid residues	4.0 (No residue produced)
Gaseous residues	4.0 (Very little residue produced)
RECYCLING AND DISPOSAL	
Materials choice	3.5 (Only minimal wastes thrown away)
Energy use	3.5 (Only minimal energy use)
Solid residues	3.5 (Only minimal residue produced)
Liquid residues	3.0 (Some water used in washing dishes and utensils)
Gaseous residues	3.0 (Some residue produced in transport)

Scenario 3: The Far Future (20 years later)

- Market incentives
- Rendering
- Animal food plant
- POTWs
- Technology development to reduce and recycle

Table 6 Matrix for Far Future Scenario

Life Stage	Materials Choice	Energy Use	Solid Residues	Liquid Residues	Gaseous Residues	TOTAL
Pre-Manufacture	2.0	2.5	2.0	3.5	2.5	12.5/20
Product Manufacture	3.5	3.0	3.5	3.5	3.5	17/20
Product Packaging	3.0	3.0	3.0	3.5	3.5	16/20
Product Use	4.0	3.5	3.9	4.0	3.9	19.3/20
Recycling Disposal	3.9	3.5	3.9	3.0	3.0	17.3/20
Total	16.4/20	15.5/20	16.3/20	17.5/20	16.4/20	82.1/100

Generalizations:

- Pre-manufacture, product manufacture, and product packaging will be developed technologically in favor of environmental concern in the long run.
- We will consider only product packaging life stage because it is very difficult and complicated to guess pre-manufacture and product manufacture life stages.

Explanation of Scenario 3 Matrix:

PRODUCT PACKING AND TRANSPORT	
Materials choice	3.0 (Significant efforts to reduce and recycle packaging materials)
Energy use	3.0 (Some energy use in transport)
Solid residues	3.0 (Significant reduction in solid waste)
Liquid residues	3.5 (Only minimal residue produced)
Gaseous residues	3.5 (Only minimal residue produced)
PRODUCT USE	
Materials choice	4.0 (No concerns)
Energy use	3.5 (Only minimal residue produced)
Solid residues	3.9 (Very little residue produced)
Liquid residues	4.0 (No residue produced)
Gaseous residues	3.9 (Very little residue produced in transport)
RECYCLING AND DISPOSAL	
Materials choice	1.0 (Very little waste thrown away)
Energy use	3.5 (Only minimal energy use)
Solid residues	3.9 (Very little residue produced)
Liquid residues	3.0 (Some water used in washing dishes and utensils)
Gaseous residues	3.0 (Some residue produced in transport)

Table 7, below, summarizes the current and potential producers and receivers of the food supply in New Haven County:

Table 7 New Haven Producers and Receivers

PRODUCERS	RECEIVERS
Restaurants	Farms
Supermarkets	POTWs
Small markets	Animal food manufacturers
Bakeries	Fat/oil renders
Manufacturing Plants	Homeless Shelters
Local farms	Landfill
Fisheries	Incinerators
Hotels	Composting
Universities	Restaurants
Breweries	Bait
Shippers	Paving Materials

CONCLUSION

In "Designing the Ecocity," a course taught by Thomas Graedel and Gordon Geballe at the Yale School of Forestry & Environmental Studies, students investigated the different factors that make up a city. The public sector, private sector, infrastructure, food, and housing were considered throughout the class, and students were asked to consider the practicality of implementing new ideas in a city very similar to New Haven. The population for this hypothetical city was 550,000. Some conclusions were that agriculture should be present and visible, and that effective land use policies needed to be established along with community gardens and education. Most astounding was the group's finding that 122,000 hectares were needed to provide all of the nutrients and other foods needed for a city of 550,000 (Waggoner). Even when using rooftops as potential growing areas, Ecocity could provide only about 6% of the land needed to sustain its population.

The most important lesson learned from the above exercise is that urban regions need to keep in mind the origin of their food supply, and they need to recognize the potential energy lost when food wastes are discarded in municipal landfills and incinerators. The policies and group efforts we have proposed – donating salvageable food to food banks, selling unsalvageable food to swine farmers, animal feed brokers, and meat rendering firms, and composting the rest – can go a long way in reducing the high level of waste associated with the food industry. Significant additional waste reductions can result from individual efforts to reduce the amount of food that is thrown away after each meal.

REFERENCES

Anderson, Karin *et al. Life Cycle Assessment (LCA) of Food Products and Production Systems Part I: LCA Methodolgy and Part II: LCA and Foods.* Swedish Waste Research Council (AFR). Stockholm, November 1993.

Chertow, M. *New Haven Regional Revitalization Project* Grant Proposal. 1997.

Foodservice and Packaging Institute, Inc. *Turning Solid-Waste Problems into Solid-Waste Solutions.* 1993.

The Greater New Haven Chamber of Commerce (GNHCC). *Greater New Haven, v. 15 n 1* (February-March 1998).

New Haven Online: *Programs Offered by the Office of Business Development* (website) Http://www.cityofnewhaven.com/economic/eco3.htrn

Resources for Sustainability Efforts: *Linking Sustainable Community Activities to Pollution Prevention: A Source Book* (website). Http://www.rand.org/publications/A4R/MR855/Mr855.ch4.html. April 1997.

Waggoner, Paul E. 1997. Feeding Eco-City. Presentation at Yale School of Forestry & Environmental Studies. November 5, 1997.

FURTHER INFORMATION

Buonicore, Anthony and Wayne Davis, eds., *Air Pollution Engineering Manual.* Air and Waste Management Association ed. VNR, New York 1992.

The Greater New Haven Chamber of Commerce. The Source: Membership Directory and Buyer's Guide. 1997.

Lowe, Ernie, S. Moran and J. Warren. 1997. *Discovering Industrial Ecology: An Industrial Briefing and Sourcebook.* Columbus, OH: Batelle Press.

Food Cycling Within New Haven, Connecticut: Creating Opportunities for Economic, Civic, and Environmental Progress Through Industrial Symbiosis
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ABSTRACT
The overall goal of this project was to formulate a set of economic development objectives that draw on food-related industrial symbiosis opportunities in New Haven, Connecticut. Our research and analysis looked at existing food sector operations within the city's boundaries and incorporated potential new businesses that might be established in New Haven, especially in the waterfront district. While the context of the project necessarily focused our work on the industrial ecology aspects of the analysis, we address social issues, quality-of-life considerations, and other factors when they are particularly significant to the rationale behind or operation of the proposed industrial symbiosis opportunities.

PROJECT BACKGROUND

Our analysis builds upon an earlier Yale School of Forestry & Environmental Studies industrial ecology project that also focused on food-related industrial symbiosis opportunities for New Haven (see Drummond *et al.*, "Efficacy of Industrial Symbiosis for Food Residues in the Greater New Haven Area," 1998 in this volume). The earlier project included a characterization of different types of food operations within the city, a description of material inputs and outputs, and short-, medium-, and long-term proposals for creating industrial symbiosis among various kinds of food-related businesses. We have incorporated certain components of this work within our analysis, although the waterfront development focus of this paper, along with the findings of our own research, have led us in a slightly different direction in terms of the scope of our project and the nature of the industrial symbiosis plan we recommend.

The earlier group focused largely on composting, food charities, and economic development via the establishment of a rendering facility and an animal feed manufacturer in New Haven. In our plan, we attempt to provide a wider array of economic development possibilities that meet a different set of criteria than those relevant to large-scale rendering and pet or livestock food manufacturing. We explain these criteria and our rationale when we introduce the industrial symbiosis case studies.

New Haven and Industrial Symbiosis Context

The set of criteria we established for selecting the scenarios was based in large part on our research on eco-industrial park (EIP) development and other initiatives designed for implementing industrial symbiosis practices. Through this research, we encountered numerous examples of different byproduct uses and other industrial symbiosis applications involving food "waste" and the residuals of food product manufacturing. The organic, nutrient-rich nature of food residuals makes the food industry an excellent candidate for industrial symbiosis. Indeed, many of the more successful EIP applications and similar projects (e.g., the Kalundborg, Denmark network) incorporate at least one example of food-related industrial symbiosis linkages.

Although it is somewhat surprising for a high-density, urban setting, the city of New Haven already has the capacity for a large number of wastestream linkages among both existing and potential food production, processing, and wholesale or retail operations. In fact, due to the limited time frame for the project, it was beyond our scope to produce a comprehensive industrial symbiosis plan that encompassed all the kinds of food flows and levels of the food industry, much less all individual food establishments, within the city. We focused instead on exploring a handful of relatively proven applications that offered promising economic development opportunities and are uniquely suited to the existing physical and institutional infrastructure and other characteristics of the city. In addition, while economic development remained at the forefront of our scenario selection and preparation process, the industrial ecology focus of the project precluded complete feasibility evaluations of the proposed industrial symbiosis undertakings. This would necessitate analysis of markets profitability, potential regulatory barriers, and other long-term planning considerations.

ORGANIZATION OF REPORT

To provide context for our recommendations, in the next section we provide a brief overview of New Haven's food-related sectors. We include a portrait of the food industry's role within the historical, cultural, and economic development of the city and a sketch of the general water, energy, and materials flows associated with food within the geographic area. This contextual information is important in order to appreciate the unique role that food has played in the life of the city and the potential that food offers with regard to industrial symbiosis and economic development in New Haven.

The name "eco-industrial park" (EIP) originally referred to the physical setting for co-located facilities linked by waste exchanges or other industrial symbiosis practices. In recent years, the terms "virtual eco-industrial park" (VEIP) and "eco-industrial network," have arisen to describe industrial symbiosis practices where the participating facilities are not co-located. For the sake of simplicity, unless otherwise stated, we use the term "eco-industrial park" for both types of industrial symbiosis manifestations.

In the third section of the report, we present the findings of our three case studies, which comprise the different components of our economic development plan based on opportunities for food-focused industrial symbiosis. Finally, in the concluding section, we address the proposed industrial symbiosis projects in the aggregate, discussing lessons learned from our analysis as well as recommendations for the city with regard to moving food-related industrial symbiosis forward from paper to development within New Haven.

BRIEF HISTORICAL AND CULTURAL PORTRAIT: OYSTERS AND OTHERS

The food industry played a momentous role in shaping New Haven from its earliest settlement when Native Americans traveled to the area to take advantage of its fertile marshes filled with oyster beds and other aquatic food resources. During colonial times, oysters in particular were an important source of food. Starting in the Revolutionary period, New Haven's harbor grew in prominence as a significant distribution point for seafood and other goods to the colonies up and down the Atlantic seaboard. In the nineteenth century, oysters remained a key industry for New Haven. Food production, processing, and distribution also grew significantly during this time to meet the needs of the burgeoning population that was drawn to New Haven and other Connecticut locales by the booming manufacturing industry and associated harbor shipping activity.

The population of New Haven was "between four and five thousand souls, including about 115 free blacks, and some 85 slaves" and there existed "41 stores selling dry goods, 42 grocery stalls, 17 butcher stalls, 16 schools, 12 inns, and five bakeries." Quoted from Dr. Wright, A Statistical Account of New Haven, 1911.

Although the majority of manufacturing activity has since left the state, the legacy remains largely in the form of food processing, which as discussed below, still occurs to a significant extent in and around New Haven. And, while unknown to many, after years of decline associated with pollution, overharvesting, and other problems, the oyster industry is for the most part flourishing once more.

The following are a few other historical and cultural snapshots of the role played by food in the life of the city:

- In the historical Italian neighborhood of Wooster Square, there are two world-famous pizzerias, Pepe's (est. 1925) and Sally's (est. 1938). The fight over which pizza is better continues, and the wait to be seated is measured in hours. Frank Pepe of Pepe's, according to legend, introduced pizza to the United States. Frank Sinatra and Hillary Clinton are only two of Sally's many well-known fans.
- At one time, New Haven had as many as six breweries. According to some, the minerals in the local water contribute to the unique quality and flavor of the historically popular New Haven beers (as well as the local pizza). Supposedly, Yale's library system owns more books on brewing beer than any other in the nation.

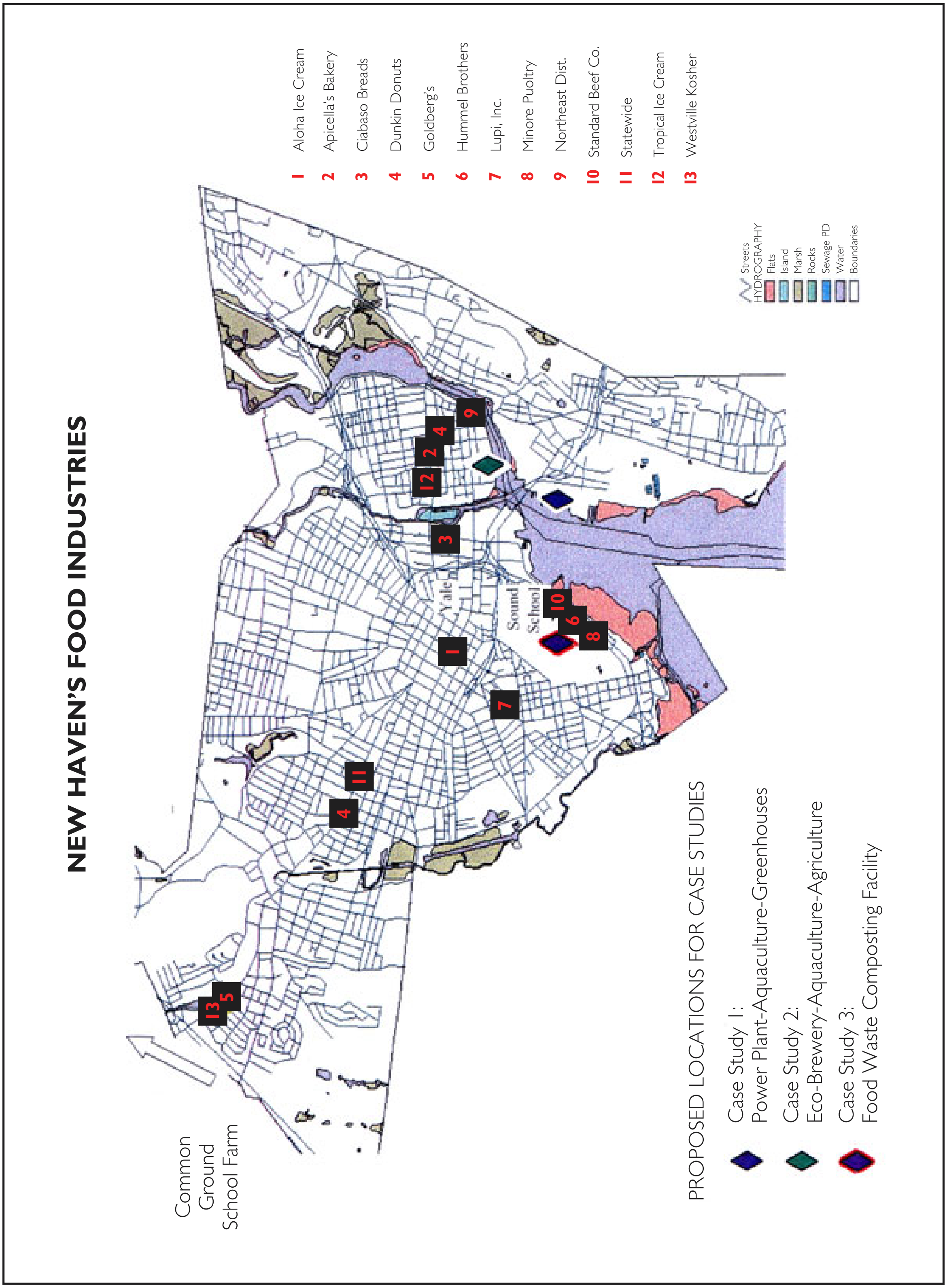

Figure 1 Map of New Haven's Food Industries

- In addition to the American version of pizza and the lollipop (invented in New Haven by the Bradley Smith Candy Co. in 1892), the hamburger is supposed to have originated in New Haven. The third generation family owners of Louis' Lunch on Crown Street claim that the then-wagon served the first hamburger sandwich in 1895.

ECONOMIC IMPORTANCE AND MAJOR PLAYERS

The food industry is still a significant sector in the New Haven economy. The city has four major bakeries, which together account for more than $20 million in annual sales (U.S. Department of Commerce 1997). New Haven has four meat and poultry plants that earn more than $50 million in annual combined sales. In addition, the city has welcomed a vegetarian burger and hot dog manufacturing company since census data were last collected. New Haven is also home to two ice cream manufacturers with more than $2 million in combined annual sales. Table 1 provides basic data on some of the major players in the New Haven food sector. The general locations of these businesses are shown on the map in Figure 1.

On the retail side of the industry, New Haven has approximately 250 establishments, including more than 85 full-service restaurants, almost 90 food stores, and over 30 special food service operations (e.g., caterers) (Dunn and Bradstreet 2001). Together these retail establishments account for about $155 million in annual sales. New Haven restaurants regularly attract visitors from all over the world.

The Long Wharf Food Terminal serves many different segments of the city's food industry. In addition to the handful of restaurants and food businesses located on its grounds, the terminal has a refrigerated storage facility dedicated to incoming food supplies intended for wholesale and retail sales. The terminal facility receives food materials from 15-20 incoming semi-trucks per day and serves as a major distribution point for food throughout New Haven's retail and processing sectors (Vanacore, Jr. 2001).

NEW HAVEN'S GENERAL FOOD CYCLES

As previously mentioned, we did not complete a comprehensive inventory of the material flows and other inputs and outputs for different food-related businesses within New Haven. The earlier industrial ecology food group provided some of this information in their report. We attempted to take a highly-focused approach, emphasizing the particular flows involved in the proposed case study scenarios.

We prepared a general flow diagram for New Haven's food cycles, which proved helpful as we completed the symbiosis case study research and selection process (see Figure 2). The most interesting and surprising aspect of the material flows that we documented within New Haven's food industry is the lack of large organic waste streams that are not already being addressed through management techniques.

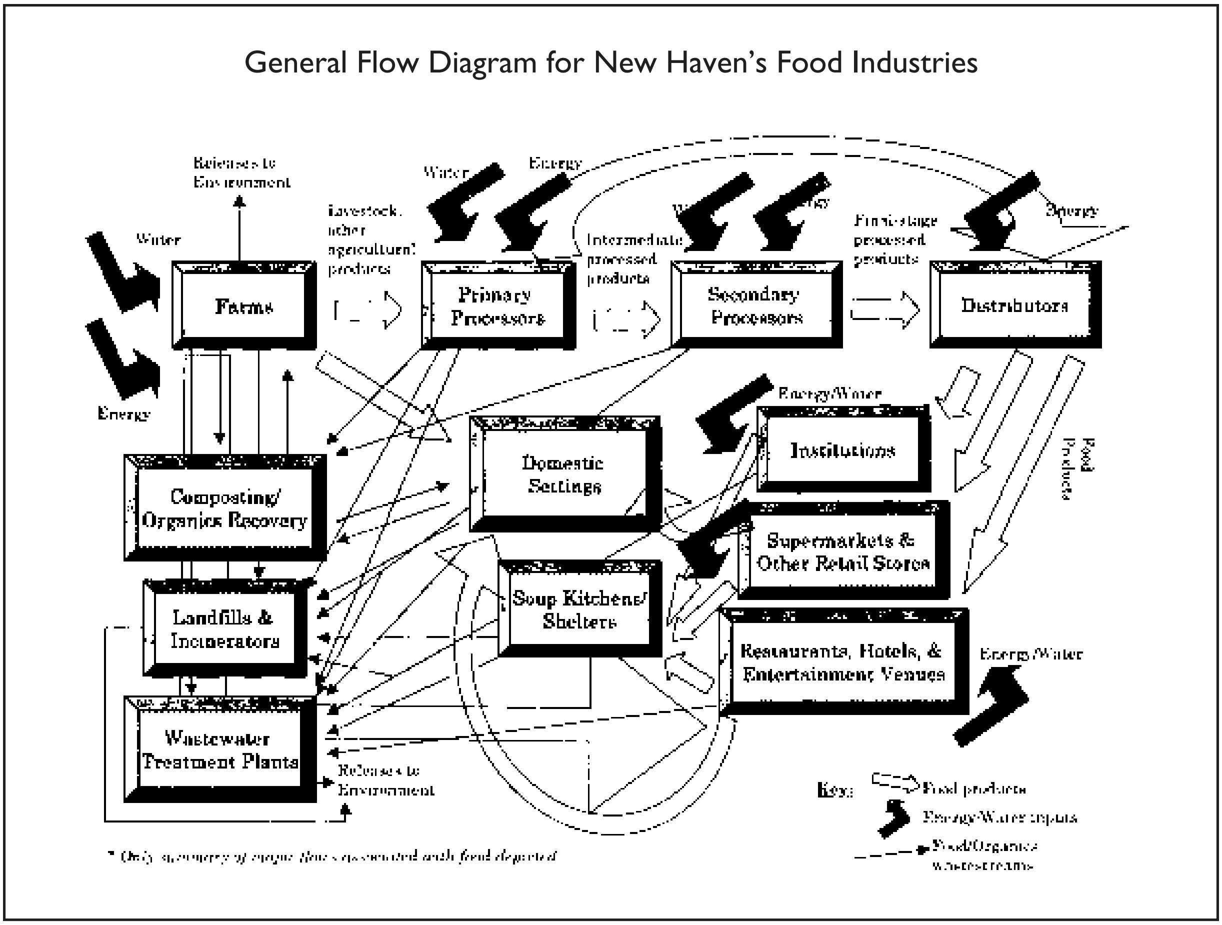

Figure 2 General Flow Diagram for New Haven's Food Industries

For example, in our conversations with Hummel Brothers Inc., a producer of hot dogs and deli provisions, we learned that the company already sends its grease waste to a recovery operation and its bones and meat scraps to a rendering plant (Aulbach 2001).

We also learned that a significant factor in reducing the number of large food waste streams produced by processors (e.g., hot dog factories) is that they increasingly receive pre-processed food materials from the intermediary processors (e.g., combined slaughterhouse and primary processing facilities). While individual processors do have food waste flows that still require attention, we found it valuable to look beyond the traditional sectors for potential industrial symbiosis opportunities.

CRITERIA FOR SELECTING CASE STUDIES

Establishing a concrete, focused set of criteria for selecting our case studies was quite important in two respects. First, the limited time frame for the project

Table 1 Representative New Haven Food Industries

A SAMPLE OF MAJOR PLAYERS IN THE NEW HAVEN FOOD INDUSTRY *(With 2000 annual sales estimates)*	
WHOLESALE/RETAIL BAKERIES	
Goldbergs 1408 Whalley Avenue $1,500,000	**Atticus Bakeries/Chabaso Breads** 390 East Street $14,700,000
Apicella's Bakery, Inc. 365 Grand Avenue $2,600,000	**Dunkin Donuts** 291 Ferry Street $720,000
Lupi, Inc. 169 Washington Avenue $1,100,000	**Dunkin Donuts** 470 Whalley Avenue $470,000
MEAT PROCESSORS	
Standard Beef Co., Inc. 216 Food Terminal Plaza $22,000,000	**Minores Meat & Poultry** 320 Whalley Avenue $9,300,000
Hummel Brothers, Inc. 180 Sargent Drive $11,000,000	**Statewide Meat & Puoltry, Inc.** 211 Food Terminal Plaza $7,900,000
ICE CREAM PROCESSORS	
Aloha Ice Cream Inc. 900 Chapel Street $1,200,000	**Tropical Ice Cream** 351 Grand Avenue $1,100,000

Source: Dunn and Bradstreet Company, Dunn and Bradstreet Report 2001.

prohibited us from examining the widest range of all possible food-related linkages. Second, from our reading of the industrial symbiosis literature, we learned that the industrial ecology context (e.g., the linkages amongst material flows themselves) is only one of several important social, economic, and other factors that determine the suitability of an eco-industrial practice for a particular location.

In other words, in this project, we wanted to identify industrial symbiosis opportunities with the best potential for being implemented successfully in New Haven in the conceivable near- to long-term future. To make this determination, we employed criteria that address the current industrial ecology in New Haven as well as the city's social, economic, and institutional conditions. We provide a summary listing of these criteria and describe them in more detail in the next section. Our criteria for selecting case studies were:

- Potential to draw on existing material, energy, and water flows within greater New Haven;
- Desirability in terms of environmental and quality-of-life issues for residents;
- Opportunities for different kinds of economic development and job creation;
- Suitability for different levels of production (i.e., ability to start small and then expand relatively easily); and
- Potential to incorporate and build on institutional and cultural strengths of New Haven communities.

Industrial Ecology and Other Environmental Considerations

The most obvious and critical first step in designing symbiosis opportunities for New Haven is identifying the existing material, energy, and water flows upon which eco-industrial practices may capitalize. As described earlier, the food sector in New Haven is characterized largely by imports of food supplies and several key food processors that have few significant unaddressed waste streams.[1] While it is possible to find some waste stream-related opportunities associated with the processing sector, a cursory analysis of New Haven's "metabolic system" for food reveals many opportunities for reducing the net export of food scrap waste from retail and institutional settings (Alexander 2001). Reducing this net export can be accomplished through food waste prevention measures and waste reuse practices, both of which offer positive economic results in the form of cost savings or new market creation.

[1] . . . processors send their cardboard and other packaging wastestreams to recycling facilities and sell their grease by-products to rendering operations.

In terms of the waste reuse possibilities, one of the most advantageous aspects of food-related industrial symbiosis is its minimal environmental impact. Numerous business opportunities that capitalize on food waste or residuals have efficient production processes and fairly uncomplicated industrial ecology budgets (i.e., when compared to other types of industrial operations). In other words, in large part due to the organic nature of food residuals, these operations require a limited set of inputs and result in relatively benign (e.g., non-toxic) environmental releases (EcoRecycle Victoria 2000).

For those food waste reuse processes that have more complicated industrial ecology budgets, again, the organic nature of the material often implies straightforward solutions for dealing with more complex inputs and potential environmental releases. For instance, nutrient-rich food waste streams are flexible with respect to how (i.e., the size and type of production process) and for what (i.e., the general product type or specific product grade) the residuals are used. In one simple example, the same food scraps that can be fed to livestock can also be an input to anaerobic digesting technologies that produce energy. For another example, different qualities or grades of soil amendments can utilize a spectrum of food waste inputs with different levels of contamination from non-organic materials (e.g., plastics). In short, EIPs usually need some level of flexibility in order to succeed over the long term (Industrial

Economics, Inc. 1998). When identifying symbiosis case studies, we kept flexibility considerations in mind, especially those that address the need for making the most out of vacant space within the densely developed New Haven area.

Flexibility and the potential for multiple, alternative uses of space relate to other criteria that are critical to the public support of and consequently to the success of EIP opportunities. The trend of community resistance to many kinds of traditional industrial development extends into the eco-industrial realm. Many residents, including those of New Haven, have expressed concern about having recycling, re-manufacturing, and other types of facilities into their neighborhoods.[2] Resident opposition to industrial facilities is often related to environmental issues and related quality-of-life concerns. This includes fears about health hazards from increased pollution, a degraded image of the neighborhood, and safety concerns associated with heavy truck traffic and other traditional industrial infrastructure. In light of these concerns, we attempted to select development plans that involve low-polluting industries and operations that would also bring positive dividends (e.g., aesthetic enhancements, increased opportunities for community-building) into the city's neighborhoods.

Economic Development Considerations

Basic issues of profitability were factored into the case study selection process. For instance, we searched for industrial symbiosis practices with potential market niche applications. At the same time, we looked for waste reuse applications that generate real savings for food-related operations in terms of reduced or avoided disposal costs. Finally, we searched the industrial ecology literature for symbiosis applications with proven records of accomplishment for economic viability.

The flexibility inherent in many kinds of food-related industrial symbiosis practices also has meaning for other kinds of economic development criteria that we felt were important for New Haven. For example, we attempted to identify development opportunities in which production could start at a low level and then grow relatively easily. This characteristic is important for several reasons. First, small-scale development opportunities provide the potential for economic benefits to extend directly into the community through the creation of small business entrepreneurs. Especially important for New Haven, flexibility in production processes and scale can help make development efforts suitable for smaller parcels of land when large properties are lacking. In addition, the ability to start an operation at a small scale makes industrial symbiosis implementation more achievable in the short term. In our review of EIP literature, we found that lengthy start-up processes and difficulty in showing progress in the early stages are some of the most significant obstacles to moving forward with industrial symbiosis and other eco-industrial development practices.[3]

[2] A resident of Fair Haven expressed his concerns about the number of waste handling companies seeking permits for his community at the April 11, 2001 presentation of the industrial symbiosis projects.

[3] See Research Triangle Institute's report, Eco-Industrial Parks: A Case Study and Analysis of Economic, Environmental, Technical, and Regulatory Issues. Executive summaries of report sections are available on the Internet (March 28,2001): http://www.rti.org/units/ssid/cer/parks.cfm.

Institutional Capacity Considerations

As previously discussed, food-focused industrial symbiosis development seems to be a natural choice for New Haven, given the relevance of food to the history and culture of the city. In addition, for a city its size, New Haven possesses a uniquely strong institutional capacity related to food products and the environmental implications of their production and overall life-cycle. The agricultural programs of the city's charter and magnet high schools (i.e., the Sound School and Common Ground High School), the Connecticut Agricultural Experiment Station, food charities such as Rachel's Table, the Yale School of Forestry & Environmental Studies, and Yale University are some of the New Haven institutional resources that we have identified as potentially helpful for food-related industrial symbiosis efforts. In selecting the case studies, we placed high priority on those operations that could draw from and build on existing infrastructure and institutional capacities within New Haven. The ability to leverage such resources is not only important to the success of symbiosis opportunities but also helps to ensure that development projects will contribute to the social and economic well-being of the city and the larger geographic region.

METHODOLOGY FOR CASE STUDIES

Once we had selected the case study projects, we conducted case-specific research efforts, drawing on both primary and secondary sources. Where possible, we completed interviews and gathered information from food industry representatives and others with expertise on and insight into our proposed industrial symbiosis scenarios. We relied heavily on a variety of secondary sources, including industrial ecology literature, food sector publications, and advertising materials and other information on tourism and the food industry in New Haven and the southeastern Connecticut region. In completing our analysis, we have drawn on the tenets and approaches of industrial symbiosis and industrial ecology overall, specifically referencing tools and concepts where we deemed them most helpful.

CASE STUDY 1
ECONOMIC DEVELOPMENT THROUGH RESOURCE CASCADING: HARNESSING POWER PLANT WASTE STREAMS FOR FOOD PRODUCTION

Introduction

Even in preparing a food-focused analysis of industrial symbiosis opportunities for the city, the significance of the Harbor Station and English Station power plants cannot be ignored. A quick glance at an aerial map of New Haven Harbor gives one an immediate appreciation for the physical and economic influence of power plants in the region and the importance of incorporating them into any new industrial development plans. In addition to their shared dominance of the city's waterfront skyline with their line-up of oil tanks, the potential industrial ecology budgets represented by the electricity generating operations make the two power plants obvious potential candidates for symbiosis opportunities.

In fact, electricity generation plants act as anchor facilities in a number of successful industrial symbiosis cases, including the original example of Kalundborg, Denmark. Power plants are strong candidates for incorporation into industrial symbiosis schemes because, depending on their fuel source and other process characteristics, the facilities generate large, fairly consistent waste streams of materials, including gypsum, fly ash, water, and heat in the form of cooling water and process steam (Gertler 1995). Of particular interest to food processing and some food production operations are the process steam and cooling waters, which are cheap, abundant heat sources. The high energy needs of such operations make these byproducts especially valuable (EcoRecycle Victoria 1999). At Kalundborg and other locations adjacent to power plants, separate businesses, or sometimes the plants themselves, operate aquaculture and greenhouse agriculture facilities to take advantage of the heat by-products. Both types of facilities have high heat input needs, and as we describe below, both offer substantial economic development potential in conjunction with the power plants.

Description

The main variable in this industrial symbiosis scenario is the production level of the participating power plant and thus the amount of heat by-product generated. Because we lacked exact data on the current heat wastestream for Harbor Station and the expected heat wastestream for English Station (should the plant be reopened), we assumed general figures for the power plants and also considered their processes and production levels to be interchangeable.[4] This assumption is adequate given the streamlined nature of our analysis and the uniformity of the by-product in question. While the steam by-product can be put through a condensation process for use in this scenario, for the sake of simplicity, we have focused on the high-temperature cooling water, which can be transported directly via pipe to an adjacent agricultural complex.

Once transported to the agricultural complex, the cooling water may be run through a piping system to heat water for fish farming or to raise the ambient temperature of greenhouses for crop production. (See Figure 3 for an illustration of all the linkages involved in this case study.) With slight adjustments to the heating system at the agricultural complex's end, the operation may be able to produce a variety of fish and crops with different temperature requirements. As a result, the decision about which types of fish or crops to produce often depends on market demand factors.

[4] The lack of exact data is due in part to the fact that Harbor Station recaptures the high-pressure steam before releasing it into the harbor, and the residual low-pressure steam is difficult to estimate. (Personal Communication with Amit Kapur, School of Forestry & Environmental Studies doctoral student and member of the Harbor Station industrial ecology class group, April 11, 2001).

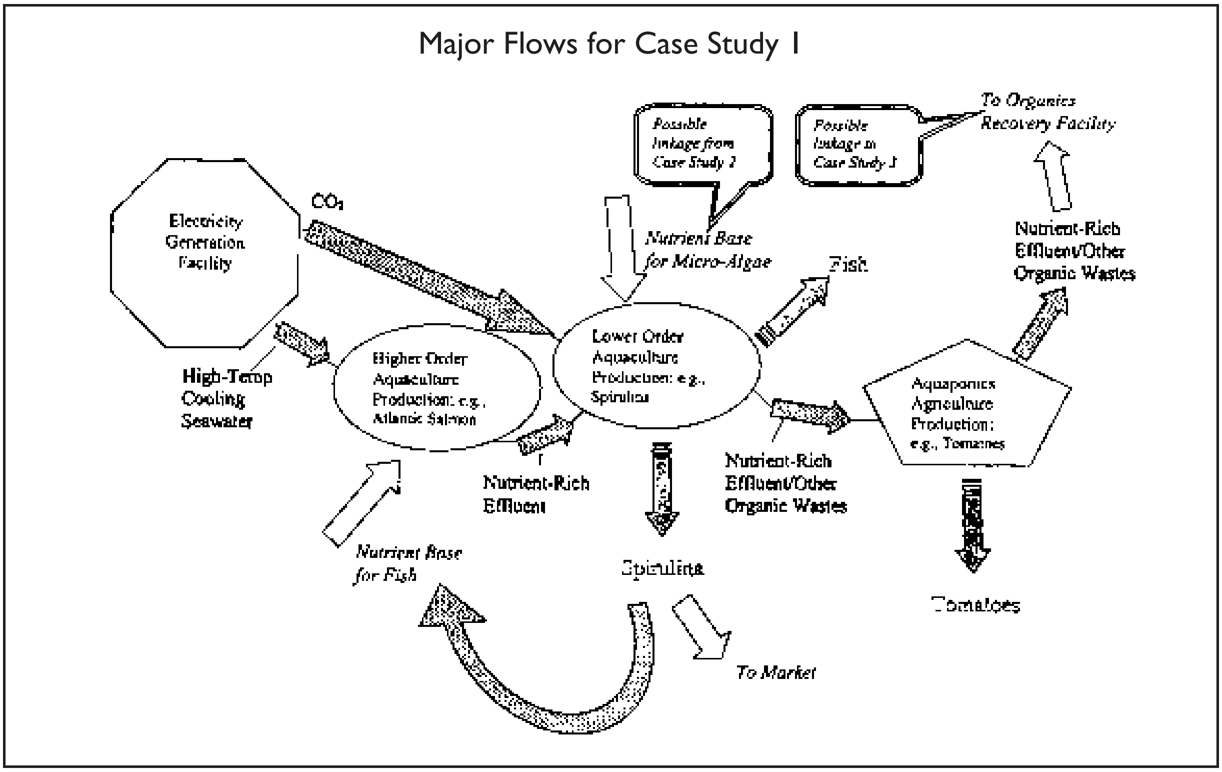

Figure 3 Major Flows for Case Study 1

With regard to aquaculture, both freshwater and saltwater species could be produced. In the case of the former, the heat transfer from the power plant cooling water would occur indirectly through the piping medium, and the fish production tanks themselves would require a separate supply of fresh water. For saltwater species, the cooling seawater could be sent directly into the production tanks. We propose cultivation of a saltwater species, such as Atlantic salmon, for the case study scenario in order to avoid the need for the fresh water supply. In terms of the crop production, again, a number of fruits, vegetables, and other plants could be grown under this scenario. We propose tomatoes because other greenhouse operations have had success in growing modern varieties and because New England's demand for the fruit must be satisfied by indoor production facilities during the long winter season.

Regardless of the species chosen, the kind of facility best suited for New Haven is an enclosed structure for both the crops and the aquaculture production. While the temperature control and contamination prevention benefits of indoor production are obvious for both crops and fish production, the ability to reduce evaporation from the fish tanks during the summer months is another advantage (Parker *et al.* 2001). Appropriate indoor structures or greenhouses are relatively straightforward and inexpensive to design and construct as far as production facilities are concerned. A weather-proof glass shell and a piping system are the main requirements for both the crop production and aquaculture facilities. Aquaculture operations also require tanks of adequate size and air pumps to maintain the oxygen levels within the tanks (Parker *et al.* 2001). Apart from these major structural requirements, both types of agricultural production allow a good deal of flexibility in terms of facility configuration, which is a bonus for a city with vacant parcels of land sandwiched between other industrial operations.

To make the most out of the opportunity for symbiosis, we suggest a specific configuration for the agricultural complex that draws on additional resource cascading practices suggested in the literature. First, the aquaculture production facility should be designed as a sequential, polyculture operation. This entails cultivating a lower order species "downstream" from the tanks of Atlantic salmon, the primary species for the scenario. In this way, the nutrient-rich effluent that results after running the cooling seawater through the salmon tanks can be put to beneficial use by supplying nutrients to another species under cultivation (Global Aquatics 1998). At the same time, this system allows the operation to avoid the costs, as well as potential environmental impacts, of disposing of a nutrient-rich – and therefore highly polluting – wastestream. This particular configuration also greatly increases the efficiency of polyculture fish production; by putting the lower order species with the correspondingly lower oxygen requirements later in a sequential system, it reduces the need for oxygen injection overall (Global Aquatics 1998). The operation of pumps for oxygen injection is one of the main factors behind the high energy demands of many aquaculture operations.

Researchers have suggested that carbon dioxide emissions from conventional power plants may be harnessed and then processed to meet the growth requirements of spirulina under cultivation (Parker et al. *2001)*

Again, many species may be chosen to fulfill the role of the lower order organism in the sequential model. For the New Haven case study, we propose the micro-algae, *spirulina. Spirulina* is used for a variety of commercial product applications, ranging from pigments to pharmaceutical products to nutrient sources for farm-raised fish. *Spirulina* also grows in brackish water, and besides having low oxygen needs, the micro-algae actually require carbon dioxide as a carbon source for their photosynthetic metabolism (Richmond 1986). This requirement introduces an additional interesting component into the industrial symbiosis model: researchers have suggested that carbon dioxide emissions from conventional power plants may be harnessed and then processed to meet the growth requirements of *spirulina* under cultivation (Parker *et al.* 2001). Furthermore, depending on the primary species under cultivation, an aquaculture operation may choose to capture some of the value of the spirulina within the system itself by using a portion of the produced microalgae as a nutrient source for the higher order fish species.

With regard to the crop production segment of the scenario, the optimum configuration enables the operation to utilize the nutritional value of the effluent produced by cultivation of the higher and lower order fish species. After the power plant cooling water is used to supply water and heat to the tanks of the primary and secondary fish species, it can be captured within trays or other platforms designed specifically for the purpose of a growing medium for the tomatoes. The name of this system design is aquaponics, which refers to the production of crops using wastewater and organic matter from cultivated aquatic organisms (Global Aquatics 2001). Aquaponics introduces a significant level of efficiency into the agricultural operation in this scenario, plus it provides the potential for higher quality crops than those grown under more traditional forms of hydroponics (i.e., greenhouse production of crops using water as the growing medium). The organic content of the growing medium for aquaponic cultivation produces healthier, more flavorful fruits and vegetables than does a growing platform consisting of water and chemical fertilizers and other additives, which dry out the roots of the plants (Global Aquatics 2001).

Following production of the fish species and tomatoes in this scenario, the organic waste that has not been put back into the system can be taken off-site for recovery. In this industrial symbiosis context, we recommend a recovery system such as composting of the waste for use as fertilizer or other soil amendments. This method generates value for any remaining waste from the production scenario and also avoids disposal costs.

Aquaponics introduces a significant level of efficiency into the agricultural operation in this scenario, plus it provides the potential for higher quality crops than those grown under more traditional forms of hydroponics

Benefits

This symbiosis configuration provides several major economic and environmental benefits, some of which have already been mentioned in the description of the operation. Environmental benefits include avoiding releases, not the least of which is the injection of high-temperature cooling water back into the harbor. Thermal pollution emissions into the water near power plants can negatively affect organisms in the Long Island Sound ecosystem, including the oysters (Gadwa 1995). The reuse of the power plant cooling water can also increase the overall efficiency of conventional electricity generation. While figures for potential efficiency gains are not available for New Haven's power plants under this scenario, Nicholas Gertler's research at Kalundborg, Denmark found that the energy cascading practiced there increased the efficiency of coal burning from 40% to as high as 90% (Gertler 1995).

As already discussed, the increased efficiency of the aquaculture and aquaponics systems also translates into greater profitability. The economic growth potential represented by aquaculture in general is by now widely recognized, though as more operations enter the sector in the United States, it will be helpful for businesses to incorporate process and product differentiation, such as that implied by the case study scenario. An environmental market niche could become significant, as the heavy industrial ecology budgets (i.e., large energy consumption, environmental releases of waste streams) of traditional aquaculture operations become more widely known. Perhaps most important of all is the role that production of spirulina and other micro-algae species might play in New Haven's larger biotechnology-based development plan, as potential applications of such species continue to mushroom in the pharmaceutical industry and other sectors (Parker *et al.* 2001).

Depending on the level of production that is implemented, the proposed industrial symbiosis scenario most likely would not generate a large number of permanent jobs after the completion of construction. That said, the operation could produce several higher level jobs requiring specialized skills in the planning and maintenance of intensive aquaculture and aquaponics production. Professional jobs and skill-building opportunities could also arise in the marketing and distribution of the specialty fish and tomatoes as well as of the remaining nutrient-rich wastestreams at the end of the sequential operation.

Obstacles

While one of the more long-standing examples of successful industrial symbiosis applications, the scenario described above would almost certainly generate skepticism and reluctance on the part of the power plant owners. A fairly significant incentive for linking to an aquaculture and aquaponics operation would most likely be required. The rising costs of electricity generation, and continued or increasing regulatory and community pressures on conventional power plants may provide such an incentive. It would be interesting to explore the possibility of a negotiations scenario in which neighboring communities shared the profits from the agricultural operations in exchange for agreeing to allow the English Station power plants to be brought back online.

It would be interesting to explore the possibility of a negotiations scenario in which neighboring communities shared the profits from the agricultural operations in exchange for agreeing to allow the English Station power plants to be brought back online.

With regard to logistical issues, the main obstacle or constraint lies in the importance of co-located operations for this case study scenario. While the design and construction of the aquaculture and aquaponics facilities as described above are fairly straightforward and inexpensive overall, the piping system that transports the power plant cooling water to the downstream operations represents a critical variable. Standard planning procedures would require that the agricultural facilities put back-up heat and water supply mechanisms in place for emergencies, but both these operations and the power plant could face economic damage, as well as potential liability concerns, should the cooling water transport pipe rupture or suffer other major structural injury. As the distance and complexity of terrain covered by the piping system increases, the potential for these sorts of problems rises, along with the costs of pipe-laying and maintenance and probability of heat loss.

Proposed Site

In selecting a site in the New Haven Harbor area for this industrial symbiosis scenario, the most important criteria, as mentioned above, is proximity to the participating electricity generation plant. In a full-scale feasibility and options analysis for the proposed development, one would compare production levels, characteristics of specific adjacent properties, and other factors across power plants and make a site selection decision based on findings from that research. In our abridged analysis, we have based the site selection on a set of more general but still important criteria.

As shown on the map in Figure 1, we selected land adjacent to Harbor Station for the proposed symbiosis development. A primary reason for the selection of this site is the continuing uncertainty about whether or not English Station will be brought back online and, if so, whether or not the plant would stay at consistent generation levels given the current public opposition. Also, from the perspective of plans for the harbor region overall, we observed that the proposed aquaculture and aquaponics facilities are quite compatible with the parcels of land sandwiched in between the tank farms when considered against other possible development options. As planners and tank owners consider other uses for the tank farm properties, perhaps some of the existing tank infrastructure could be converted to use in the cooling water piping system or for the agricultural structures themselves. Finally, we determined that co-location near Harbor Station is convenient for both highway and harbor shipping traffic, which would provide for easier transportation and distribution of the fish, tomatoes, and other products generated through the industrial symbiosis linkages.

CASE STUDY 2
ECONOMIC DEVELOPMENT THROUGH INTEGRATED BIOSYSTEMS: ADAPTING THE FIJI MONFORT BOYS' TOWN MODEL TO NEW HAVEN

Introduction

In the realm of industrial ecology, the concept of an integrated biosystem (IBS) approach linking brewery waste to agricultural production is probably even more well-known than the power plant scenario described in the previous section. The prominence of this industrial symbiosis scenario is due in large part to the ground-breaking work performed by George Chan and other researchers at Zero Emissions Research and Initiatives (ZERI). In the most well-known example of this scenario – and one of the most widely acclaimed examples of industrial symbiosis in general – Chan and others helped to design an integrated biosystem at a home for disadvantaged boys on the island of Fiji. This system uses the sludge from a brewery as fuel for electric power and as nutrient input for student-managed production of mushrooms, vegetables, livestock, and fish (Kane 1997). Begun in the late 1990s, the system at the Monfort Boys Town near the capital of Suva has experienced a good deal of success and regularly receives visits from interested industrial ecologists from around the world. The concepts employed in the Monfort IBS have been transferred to projects in several other locations, including a community development project in Tsumeb, Namibia and a small business in Newfoundland.

This system uses the sludge from a brewery as fuel for electric power and as nutrient input for student-managed production of mushrooms, vegetables, livestock, and fish (Kane 1997).

Many existing and planned IBS ventures have community and personal capacity-building and grassroots economic development among their top priorities. These goals are well-suited to a potential IBS venture in New Haven for several significant, interrelated reasons. First, the densely populated landscape obviously precludes large-scale agriculture so that a New Haven IBS venture, bound to the city limits, would by necessity be implemented at a micro-enterprise level. This small scale of operation offers on-the-ground opportunities for entrepreneurs who are gaining agricultural production, business management, and other skills necessary for economic development by way of the suggested IBS application. Second, several educational institutions in New Haven train students for careers in agriculture and aquaculture. Current and future graduates of these programs will be able to work in and advance the IBS ventures in this industrial symbiosis case study.

Description

In this industrial symbiosis scenario, the anchor facility – a brewery – would need to be established in New Haven. Dating back to the nineteenth and early twentieth centuries, New Haven has a strong brewing tradition to go along with its historically strong food industry base. As recently as the late 1990s, New Haven still had a micro-brewery, the Elm City Brewery, which was quite successful for several years until business mismanagement and other factors forced it out of operation. Beyond supplying the major waste stream for this symbiosis scenario, we believe that a micro-brewery or micro-brewery-and-restaurant combination is a viable small business development option for the city. Across the nation and especially in the New England region, there is strong demand for place-specific, "local flavor" micro brews. In addition to the score of successful micro-breweries in Massachusetts, Vermont, and other New England states, Connecticut has its own models in the form of the Hammer and Nail brewery based in Waterbury and the New England Brewery of Norwalk (Elser 2001).

For the reasons discussed above, a micro-brewery, rather than a large-scale brewing operation, is the appropriate size for the IBS application described in this case study. This size of brewery corresponds to approximately 10,000 barrels of beer a year, while a larger commercial brewery might put out 200,000 barrels during the same time period (Elser 2001). Beer can be brewed using a number of different grains and manufacturing processes. Breweries involved in IBS practices use various grains as well, ranging from barley to a combination of maize and sorghum (ZERI-Germany 1998; ZERI 2001). While the grain variety is not generally considered to be very significant to the functioning of the IBS aquaculture or agriculture components, research has found that certain kinds of spent grains are better than others for the production of bread. ZERI recommends spent barley as the best substitute for flour, so we assume that the proposed brewery uses that grain in this case study (ZERI 2001).[5]

[5] The brewing process is not as important to the workings of an IBS and so is assumed to be a given in the case study analysis.

Following the brewing process, the next links in this IBS scenario are to the bread-making and mushroom production operations (see Figure 4). In the case of bread production, the process is exactly the same as under normal bakery operations except that the spent grains from the brewery are "pulped" and ground to act as the substitute for the flour. The process for the mushrooms is just about as straightforward. Again the spent grains are "pulped," and then the waste is mixed with grass, rice straw, or other fibers since the fiber content of the spent grain itself is too low for successful mushroom cultivation (ZERI-Germany 1998).

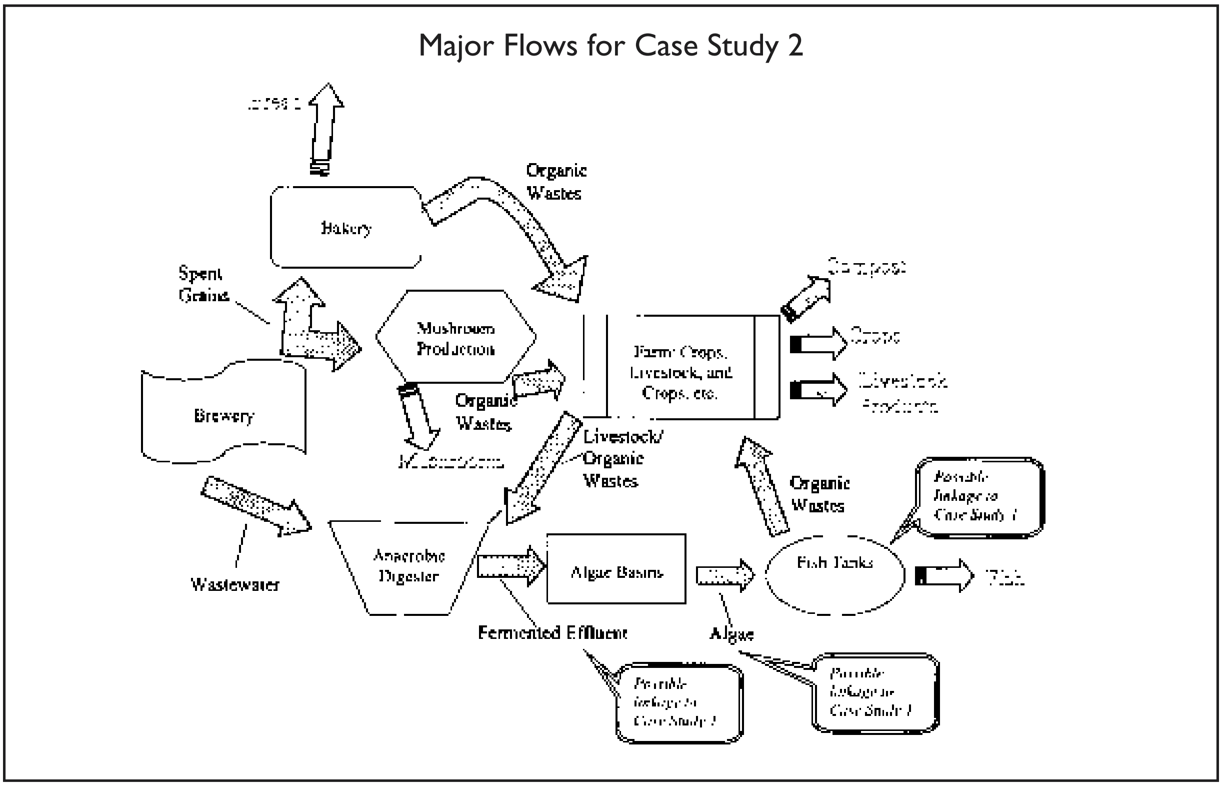

Figure 4 Major Flows for Case Study 2

Next, the material is packed into plastic storage bags and pasteurized. At this point, the bags of growing substrate are planted with the mycelia of the mushrooms and then stored in any sort of indoor structure. This process is essentially the same whether cultivating oyster, shiitake, straw, or other varieties of mushroom that grow successfully on the brew-waste substrate system. Depending on which variety is cultivated, the mushrooms will begin to fruit after approximately four to five weeks. The main requirements for the mushrooms during the cultivation time are adequate moisture and a stable ambient temperature of approximately 75º F.

Following the mushroom cultivation process, the spent grain substrates can enter the agricultural operation as feed for pigs, chickens, or other livestock or as material for vermiculture (i.e., worm-aided composting).[6] Depending on the quantity of available brewery waste and the desired levels of production at the mushroom cultivation and agricultural operations, the resulting fertilizer

[6] Organic waste streams resulting from the bread-making operation may also be used for the same agricultural purposes.

or other soil amendment product can be sold or put toward the farm's own crops.

The waste generated by livestock in the agricultural operation may contribute to the production of soil amendment products, or it may be directed to a very different potential component of the IBS: anaerobic digester technology for brewery waste reprocessing. In this stage of the IBS scenario, the effluent left over from the brewing process – and separated from the "pulped" spent grains – is fed into an anaerobic digester. Various kinds of anaerobic digesters exist, but the basic goal of the technology is to encourage the growth of anaerobic bacteria within a sealed container so that these bacteria will digest, or break down, wastewater with high organic content into a superior effluent of basic nutrients (ZERI 2000). The resulting effluent becomes the nutrient source for algae, which then are used to support the growth of fish in aquaculture tanks. The waste stream resulting from the aquaculture component can be sent to the farm to be spread on crops as a nutrient-rich form of fertilizer.

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Because the IBS involves agriculture and food production cycles and associated organic waste streams, an almost limitless number of combinations of symbiosis linkages is available to the operators of one or more of the individual components in the system. There are also several different options related to the number of separate businesses or entities that can participate in the loop. In other words, the Monfort Boys Town case represents the centralized model, while it is also foreseeable that a brewery, a bakery, an agriculture facility, and other kinds of operations could fulfill each of the IBS segments. In the case of New Haven, we recommend that in addition to a newly created combination micro-brewery and restaurant, two particular institutions should participate in the first attempt at implementation of this kind of IBS scenario. These two institutions are the Sound School Regional Vocational Aquaculture Center and the Common Ground High School, a charter school that focuses on agriculture and environmental sciences.

With regard to the concept of a combination micro-brewery and restaurant, we suggest that the more directly the brewing, mushroom cultivation, and bread-baking operations are tied together, the better they would be able to promote the symbiosis linkages. In other words, not only could an associated restaurant provide publicity for the house micro-brew, the menu presence of mushrooms and bread generated in conjunction with the brewing of the beer represents an opportunity for a unique promotional strategy. Even better would be to incorporate the IBS fish, vegetables, and livestock products into the restaurant menu.

For the aquaculture component, there are a few key reasons to involve the Sound School. First, in the form of its facility, staff, and other contacts, the high school represents a valuable resource for aquaculture expertise within the state. Also, with the new construction occurring on its Long Wharf campus, the school provides an almost ready-made location for the IBS aquaculture segment. Only a few modifications, such as adding an anaerobic digester, would be required before the IBS production scenario could proceed. Finally, the addition of the digester technology as well as the algae cultivation and other aspects of the industrial symbiosis scenario would be a tremendous addition to the school's curriculum, providing students with further opportunities to gain real-world knowledge about the marine and environmental sciences as well as about being involved with a business operation.

The agricultural component of an IBS scenario is undoubtedly the hardest to envision in New Haven. However, the fact that New Haven has in its midst a working farm (the New Haven Ecology Project's organic farm on Springside Avenue) makes the scenario feasible on the smaller scale that is being considered. A large part of the curriculum at the Common Ground High School (a charter school run by the New Haven Ecology Project on the grounds of the organic farm) is focused on teaching the students how to operate the on-site organic farm's production of vegetable and herb crops, as well as how to raise goats, sheep, pigs, and chickens. Again, involvement in the proposed industrial symbiosis project would provide wonderful learning opportunities that support the educational mission of the school. Furthermore, participation of both high schools in the IBS project would create a unique situation in which the two groups of students could collaborate and offer learning enrichment to one another on their focus areas of aquaculture and agriculture.

For the purchase of shares and contribution of sweat equity, residents and neighborhood and other community groups could establish IBS-related micro-enterprises that would be supported by the technical assistance and other resources of the participating institutions.

A significant indicator of success would be if the collaboration between the two schools and other institutions extended into the community, enabling city residents to benefit from the project as a sort of extension program, picking up skills that could enable them to start additional IBS projects or other kinds of ventures (the New Haven Ecology Project already offers weekend and summer community programs). Our long-term vision for how such an outcome might be brought about draws from the cooperative agriculture model. The vision casts the Common Ground High School, the Sound School, the Connecticut Agricultural Experiment Station, or a combination of these and other institutions as the leaders of an urban agriculture cooperative organization. In addition to housing educational, financial, and other resources, this organization could be responsible for further outreach to New Haven residents and community groups. For the purchase of shares and contribution of sweat equity, residents and neighborhood and other community groups could establish IBS-related micro-enterprises that would be supported by the technical assistance and other resources of the participating institutions. This model encourages the coordination that is necessary to ensure successful functioning of symbiosis linkages and also facilitates the kind of planned flexibility and oversight that viable IBS ventures draw on to grow and adapt to changing environmental, economic, technical, and other kinds of conditions (Klee 1999).

Benefits

The avoidance of environmental releases and reductions in the material budgets associated with the brewery and the participating agriculture and aquaculture operations are among the most primary benefits of the described system. For instance, the traditional process for brewing beer is highly inefficient. Between four and forty liters of water can be consumed to produce one liter of beer, and generally less than 10% of the grains are used by the brewing process (ZERI 2001). Also, unless put towards some reuse application, the nutrient-rich waste produced by both aquaculture and agriculture operations can be highly polluting to water bodies and other ecosystems, either in the form of point source releases or as unintentional non-point source releases or run-off.

While this scenario calls for the introduction of a potentially polluting brewery, the small scale of the proposed operation along with the waste reuse aspects of the IBS work to negate the waste stream concern while creating opportunities for expansion in existing aquaculture and agricultural ventures. Further, our research of the food industry and market conditions in the area suggests that a combination micro-brewery and restaurant would fill a real economic gap and could improve the image and social environment of the city. Also, the economic promise of aquaculture, and increasingly of mushroom cultivation, are widely recognized. For example, the business of shitake mushroom cultivation is more than $2 billion worldwide and the industry has been growing at a rate of around 15% for the past several years (ZERI 2001).

The most significant economic development benefits projected for this case study are, at least for the beginning stages, the building of community and individual capital rather than the generation of large amounts of financial capital. This proposed scenario looks at investment for the long term, and we envision the strengthening of business, educational, and professional skill networks, such as the suggested urban agriculture cooperative, as one of its key objectives. While the IBS itself would generate a relatively small number of jobs at the onset, the created positions would include both those requiring specialized skills (e.g., agricultural entrepreneurs and brewery and restaurant managers) and those conducive to advancement from the ground level (e.g., restaurant kitchen employees, aquaculture facility personnel). In addition, the opportunities for increased social cohesion, positive city image-building, aesthetic diversification of neighborhoods, and other more intangible but significant components of long-term economic stability cannot be overlooked.

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Finally, the flexibility of the system in this scenario would allow – or even encourage – expansion to larger scales of production by involving farms or other regional facilities farther away from the city. Such expansion would still accrue economic benefits for south central Connecticut through an increased reliance on local rather than out-of-state food product and intermediary material suppliers.

Obstacles

As previously mentioned, the proposed smaller scale for this IBS scenario precludes many of the logistical hurdles that would normally arise for this symbiosis application in a setting like New Haven. That said, there are several potential obstacles worth mentioning for this particular case study scenario. The first involves the adaptation of the IBS approaches to aquaculture and agriculture, practiced largely in the southern hemisphere, to the landscape and climate of New England. This obstacle is largely surmountable through the use of indoor production facilities for the mushrooms and the fish tanks. Also, during the winter season, an increase in mushroom cultivation, in production of soil amendments (in preparation for the spring planting season), or in the amount of food provided to livestock, which generally increases during the winter months anyway, could handle any organic waste that is not utilized for outdoor crop growth.

Another potential obstacle relates to the proposed smaller scale for the case study scenario. Agriculture and aquaculture, especially as practiced at lower production levels, are generally low profit-margin businesses. As a result, operations may experience difficulties in receiving funding or, depending on the circumstances, may not be able to rely on the agriculture or aquaculture as the only means of income. We suggest a cooperative approach, at least initially, between the Sound School, Common Ground High School, and others who are eligible for a wide range of funding sources. Once the system is up and running, the participating entities could spin the IBS off into a separate fundraising venture, contract aspects of it out to private entrepreneurs, choose to maintain it entirely under the auspices of their institutions, or invoke several other organizational structures.

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Proposed Site

If our proposed scenario were fully implemented, New Haven would become home to expanded centers of aquaculture and agriculture development at the Sound School and Charter High School. At the same time the city would welcome a new combination micro-brewery and restaurant as well as numerous community gardens, mushroom cultivation structures, and other micro-enterprise agricultural operations. With its waterfront views, attractive brick architecture, and a surplus of former manufacturing buildings and warehouses, New Haven has a number of sites that would be appropriate for a micro-brewery and restaurant. Of the areas within the harbor region, our first site choice is the River Street district located near the former English Station power plant (see map in Figure 1). The main reason for suggesting this site is that the Fair Haven community, which includes the River Street district, needs – and has space for – new development aside from traditional industries. The micro-brewery and restaurant would provide economic activity and serve as a new social meeting place, drawing residents from other parts of the city into the neighborhood. As part of the project's development, an aquaculture or agriculture demonstration site that implemented some of the IBS components might provide aesthetic enhancement and bring additional educational opportunities to the River Street area.

CASE STUDY 3
ECONOMIC DEVELOPMENT THROUGH OPTIMIZING OF FOOD RESIDUALS: IMPROVING FOOD CYCLING AT YALE UNIVERSITY AND IN NEW HAVEN'S RETAIL SECTOR

Introduction

No manufacturing or service-providing system can be properly assessed without looking at its waste. We examined the waste streams from the food cycle in New Haven and discovered several areas where food waste could be reduced, recycled, or simply reused more efficiently. In addition to being more environmentally friendly, alternative methods for addressing food waste – including, importantly, a large-scale composting facility – would provide economic benefits for the food industry and other business sectors in the city.

In addition to being more environmentally friendly, alternative methods for addressing food waste – including, importantly, a large-scale composting facility – would provide economic benefits for the food industry and other business sectors in the city.

As a state, Connecticut has the third highest tipping fees in the country, approximately $68 per ton of trash sent to landfills (U.S. EPA 1998). With available landfill space at a premium, and virtually non-existent for New Haven, many observers have proposed alternatives to dumping as a waste management strategy. In a report published by the Housatonic Valley Association (HVA), it was estimated that "composting, combined with recycling, can recover and recycle as much as 70% of Connecticut's municipal solid waste" (HVA 1991). Citing the many problems associated with landfills (e.g., groundwater pollution, growing public resentment) and with incinerators (e.g., air pollution), the HVA has observed a "renewed interest in composting" (HVA 1991).

Perhaps the Association's most relevant – and somewhat surprising – finding is that the cost of composting is now, on the average, less than other forms of waste disposal. The economics of solid waste disposal technologies are becoming more competitive. Some cities have been forced to transport trash hundreds of miles to a landfill, with hauling fees adding significantly to the overall disposal costs; the escalating costs are providing authorities with an incentive to seek less expensive methods.

In the following section, we describe our analysis of the food waste situation in New Haven, focusing on the largest retail food sector in the city, restaurants, as well as on institutional settings such as Yale University. We also discuss some ideas for improving the situation while creating economic development opportunities for the city at the same time.

Description of Food Waste Generation in New Haven

According to analyses by the U.S. Environmental Protection Agency (EPA) and others, approximately 8% of the U.S. municipal solid waste stream (MSW) is food waste (HVA 1991). While waste composition will differ somewhat across localities, for the purposes of this analysis, we will assume that the percentage of food waste in New Haven's MSW is roughly equivalent to the national figure.

In order to confirm this estimate for New Haven and to get a better sense of why food waste is being discarded into the MSW in the first place, we interviewed a number of different representatives of the city's restaurants and other food industry segments. The individuals we talked with included restaurant owners, soup kitchen employees, Yale recycling personnel, and dining hall managers. The questions we asked and the responses we received from our restaurant contacts are summarized in Table 2.

Although our formal research only included a small sampling of New Haven's restaurants, Table 2 shows several important conclusions:

- Whether motivated by profit or conscience, many restaurant owners are concerned about wasted food.
- Many restaurants are currently affiliated with various food charities, for example, Rachel's Table and the Downtown Evening Soup Kitchen (D.E.S.K.).
- The relationship between restaurants and food shelters can be strained, however, if a strict donation structure, along with patience and mutual respect, are not maintained. For instance, among several organizations, there was a feeling that charitable organizations did not understand and appreciate the rigid timetables of the business world.
- There is a lot of interest in composting among food businesses as an alternative way to handle waste. As a result, it appears that a market exists for commercial food composting in New Haven.

After talking with our restaurant contacts, we moved up the New Haven food chain to investigate waste among food processors and wholesale distributors. For example, we talked with Jaime Gongales, the manager of Chabaso Bakery. As a food processor, he receives bulk foods such as flour and eggs from the Long Wharf Food Terminal (Gongales 2001). His facility provides bread products for 170 stores in the Tri-State area (Connecticut, New Jersey, New York), including 15-20 stores in the New Haven area. The average weekly output is approximately 35-40,000 loaves of bread. If an error occurs during the baking process, which Mr. Gongales indicated occurs between 10 to 15% of the time, loaves are dumped into the garbage in order to make room for the next batch.

Based on the information that Mr. Gongales provided, we estimate that between 3,500 and 6,000 loaves of bread are discarded weekly from the bakery as MSW. The other main waste stream generated by the bakery is composed of

Table 2 Summary of New Haven Research on Restaurant Waste Handling

SUMMARY OF RESEARCH ON NEW HAVEN RESTAURANT WASTE HANDLING				
Establishment Address	**Food provider and location of pickup**	**Current method of waste disposal**	**Experience with food shelters?**	**Concerned about waste? Interest in composting?**
BURGER KING 900 Chapel St. New Haven	Burger King Distributors, no location specified. Received all ingredients pre-processed and packaged.	Throws into trash if "more than ten minutes old."	Yes, but stopped donating because of logistical problems and feeling that volunteers came "asking for food."	Not much table waste. Indifferent to composting idea.
SUBWAY 926 Chapel St. New Haven	Subway Foods Distributors, ingredients for sandwiches shipped via Long Wharf Food Terminal.	Discarded food put into garbage. Noted high costs of disposal services.	Yes, but did not appreciate lack of punctuality/reliability of donation system. Still gives away party sandwiches that are not picked up.	Fairly concerned. Would consider joining inter-business compost program if proven effective.
CLAIRE'S CORNER COPIA 1000 Chapel St. New Haven	Organic Distributor, high-quality, from-scratch ingredients shipped via Long Wharf Food Terminal.	Added to New Haven waste stream as garbage. Regretted this method and wished for a more sustainable process.	Yes. Still delivered to them when excess food is produced, but restaurant attempts to practice waste reduction practices.	Expressed a genuine interest in composting, mentioning that Yale used to run a composting program.
ATTICUS CAFÉ & COFFEE SHOP 1082 Chapel St. New Haven	Chabaso Bakery on State St. in New Haven, food delivered twice a week. Food pre-processed and packaged.	Put into trash. Alarmed by rising trash disposal costs.	Yes, occasional donations continue though not as frequently as in the past due to inconsistent pickups.	Quite concerned. Had nightly donation of leftovers but otherwise discarded stale, uneaten bread. Showed enormous interest in joining a proven compost program.

"take backs," bakery goods received back from stores, that are mostly still edible but have gone beyond the sale expiration dates. Mr. Gongales estimates that this waste stream represents approximately 10 to 15% of the quantity of product that they manufacture. He reported that Chabaso used to donate the "take backs" to Rachel's Table and other food charities, but logistical problems (such as irregular pick-ups) forced the bakery to stop this practice. The same problem was reported by several of the restaurant managers.

Turning closer to home, we performed a similar analysis on food waste at Yale University, one of the largest institutions in New Haven. C.J. May, the recycling coordinator at Yale, estimated that Commons dining hall, the largest on campus, generates about one ton of preparatory food waste per week (May 2001). Preparatory waste is the material that is discarded during food preparation; it is separate from table waste, which is left-over food on trays. Taking table waste into account, May estimates that each dining hall on campus generates a total of 3.5 tons of food waste per week. This figure translates into a yearly estimate of approximately 200 tons of food waste for all Yale dining halls combined.

Currently, Yale discards its food waste in two ways. First, nearly all of the college dining halls put food waste into the trash, which is then transported to the New Haven transfer station. Alternatively, at the Commons dining hall, food waste is disposed of as sewage and eventually enters Long Island Sound. After a reprimand from the New Haven Wastewater Treatment Plant, Commons installed a pulper to treat its waste. Since nearly 37% of solid food waste is actually liquid, pulpers are used at many institutional facilities looking to reduce solid food waste (Tellus Institute 1990).

In the past, Yale also used alternative disposal methods for its food waste. Food waste was given to a local swine farmer for livestock feed, and some of Yale's preparatory food waste was donated to shelters (May 2001). Unfortunately, both programs were discontinued due, once again, to logistical difficulties. May summarized the significant logistical issues associated with many food collection programs: "If we have a group of computers to be collected over a weekend, we can let them sit for a few days and pick them up on Sunday. The same is not true about food which spoils within a matter of hours."

In the past, Yale also used alternative disposal methods for its food waste. Food waste was given to a local swine farmer for livestock feed, and some of Yale's preparatory food waste was donated to shelters (May 2001). Unfortunately, both programs were discontinued due, once again, to logistical difficulties.

Potential Solutions

Based upon the analysis summarized above, we determined that different approaches are required for three different kinds of food waste: preparatory waste, table waste, and "take backs" or other excess but untouched food. In this section, we describe a few solutions that could be implemented in various combinations to address all types of food waste.

The first solution that must be considered is food waste prevention. A number of different strategies may be taken to reduce the total volume of food waste, and we believe that a preventative approach is especially appropriate for institutional settings, like Yale, which regard food waste, especially table waste, as an avoidable cost. One possible preventative approach for Yale is described in the Appendix.

As valuable as the preventative approach may be for institutions, it is perhaps not as promising for food processors and restaurants. These operations cannot easily change their customers' behavior with regard to the creation of food waste and generally do not want to try to influence customer attitudes about it. Furthermore, motivated by the value of ingredients, many food operations are already implementing strategies to avoid generating waste during food preparation. As a result, our proposed solutions for the food waste situation of processors and retail establishments focus on alternative means of food waste disposal.

First, with regard to "take backs" and other excess foods that are still suitable for human consumption, we feel strongly that the logistical and other problems that prevent regular donations to shelters and food banks must be addressed. We propose two measures for overcoming the logistical problems, which, if implemented, may encourage restaurants and processors to start or resume donations. The first is installation of on-site, two-way refrigerated lockers where food producers can deposit food daily; this would address some of the storage and staff time issues. The second involves an existing or new community group securing funds to act as a city-wide facilitator for overseeing frequent, regular donation pickups. While not a catalyst for economic development, the facilitation of food donation makes sense from a charitable standpoint and an industrial ecology standpoint. By helping to address issues of food security in New Haven, food donations contribute to the community-building that is requisite for any kind of urban development.

Our second food waste disposal solution would provide a direct vehicle for substantial economic development for New Haven. We propose that the city should advocate the construction of a regional composting facility. Support for this idea comes not only from our restaurant contacts but also from the Connecticut Department of Environmental Protection (DEP). Recently, the DEP launched a new project to promote recovery of food waste within Connecticut. This project has the following goals (DEP 2000):

- To identify, quantify, and map all the commercial and institutional locations in Connecticut where potentially recyclable food scraps are generated;
- To match these operations with the state's transportation network and current composting infrastructure;
- To help the state's food industry save money in disposal fees;
- To generate new economic development by encouraging the recycling of organic materials.

The main reason that DEP is undertaking this project is that Connecticut is experiencing difficulty with disposing of all the heavy, wet food waste generated in the state (Alexander 2001). By bringing in a large-scale composting facility, New Haven has an excellent opportunity to help improve its own waste disposal situation, as well as to serve the needs of other Connecticut communities while at the same time experiencing financial benefits.

Composting is defined as the controlled biological decomposition and conversion of solid organic material into a humus-like substance. While the details of the various existing composting techniques are beyond the scope of the report, all essentially fall into three primary categories: the enclosed vessel method, the static aerated pile method, and the windrow method. Depending on the composition of materials used as inputs, the different composting methods result in soil amendments of varying qualities or grades – ranging

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from high-grade compost used for horticultural applications to lower-quality compost, which can be utilized in erosion control practices.

While the exact specifications vary between composting methods and desired product characteristics, basic requirements include space for a relatively large indoor facility, a trained staff, a regimented maintenance plan, and an adequate level of community acceptance. For health and quality-of-life issues, such as odor, it is almost a necessity to have an indoor rather than outdoor facility when composting in an urban setting. In order for any large-scale compost facility to succeed, it must also attract other forms of recyclable waste to meet both required material composition and wastestream quantity levels. Including paper, yard waste, and other organics, U.S. EPA estimates that approximately 60% of the nation's MSW is suitable for composting.

Obstacles and Benefits

Upon completion of an initial scoping analysis, we concluded that composting appears to be a viable alternative to landfilling or incinerating food waste from New Haven and surrounding areas. From an environmental perspective, composting is an excellent way to reduce demand on natural resources while recovering organic material from the waste stream. From an economic development point of view, a large-scale recycling facility would create numerous jobs during construction as well as during normal operations. Depending on the design, a compost facility can be labor-intensive, requiring a staff to sort the organic materials upon delivery and to perform upkeep on the material, such as keeping it aerated during the composting process.

From an environmental perspective, composting is an excellent way to reduce demand on natural resources while recovering organic material from the waste stream. From an economic development point of view, a large-scale recycling facility would create numerous jobs during construction as well as during normal operations.

While composting is a proven process, there are few successful large-scale composting operations that can serve as a model for new facilities. Due to poor planning and maintenance, for example, a number of municipal and other composting operations in the United States have not fulfilled their expectations. Also, concerns about odor, truck traffic and unsightliness may translate into uneven community support for – or outright opposition to – large composting facilities. Operating in an aesthetically pleasing indoor facility, enforcing strict traffic safety rules, and involving the community in educational and planning activities are strategies that composting and other materials recovery facilities have implemented to earn and maintain community support (Heumann 1998; Malloy 1997; White 1992). Given the extent of the food waste problem and the real potential that exists for New Haven to become a regional player in implementing the solution, we suggest that the city and its business and civic institutions work to begin a recycling facility pilot program in the near future. Yale University, which currently pays nearly $16,000 per year to dispose of its food waste, would be a strong candidate for spearheading such an effort.

Proposed Site

For the composting venture described in this case study, we recommend vacant property in the Long Wharf area (see map in Figure 1). One of our main reasons for selecting this location, as opposed to others in the harbor district (e.g., the River Street area in Fair Haven), is concern over quality-of-life and image issues for New Haven neighborhoods that are already home to a high proportion of current or past industrial sites. In our assessment, the Long Wharf area, with a relatively high percentage of flat, vacant land and a virtually non-existent residential population, is compatible with both a composting operation and other types of development (e.g., retail stores, tourist attractions). An indoor facility for the composting can greatly cut down on noise, odor, and other nuisance concerns.

While observers may point to the less-than-optimal access to the interstate as an obstacle to development at Long Wharf, we believe the area is the most appropriate within the harbor district for additional truck traffic. Further, we believe that a composting facility at Long Wharf could provide the impetus for addressing the traffic problems in the area. Redesigned traffic patterns will be necessary for just about any type of redevelopment in the region, and will enhance the harbor's capacity for handling a range of goods.

CONCLUSION

Although New Haven is well-regarded among those who have experienced its excellence in food quality and variety, we feel strongly that the Elm City is not fulfilling its potential as a "Food Haven." Our research has shown that a number of food-related opportunities exist in the areas of tourism, industrial symbiosis, and organics recycling. New Haven has been called the "food capital of New England," a fitting name for a city whose rich history boasts the first American pizza and the world's first hamburger. Following the lead of other New England cities, like Boston and Mystic, New Haven can make better use of its reputation as a historical haven for great food while building a new image as a pioneer in food-related eco-industrial innovations.

We do not exaggerate when we say the future prosperity of New Haven is linked to its food (and food waste!). Located at the intersection of two major northeastern thoroughfares, New Haven is ideally situated to attract day-trip traffic from tourists and New England residents alike as they travel between Boston and New York. Yet many Connecticut drivers on these highways remain uninformed about New Haven's cuisine and other special attributes. The proposed tourism center adjacent to the waterfront district provides the perfect opportunity to begin linking New Haven to its exciting food history and vibrant food present. There are myriad ways to do this; we especially like the ideas of food-focused brochures, tours, fairs, and other events for residents and tourists alike. We urge the city to utilize some of its Empowerment Zone cluster-funding for the tourism industry to cultivate some projects that celebrate (and benefit from) New Haven's special relationship with food.

The potential industrial symbiosis applications that we have described in this report promote New Haven as a food-unique location. As we have attempted to convey in the case studies, the benefits of industrial symbiosis applications include diversifying New Haven's economic base, providing alternative economic ventures aimed at developing the city's poorer neighborhoods, and offering opportunities for increased social cohesion and capacity-building among businesses, institutions, and residents. We envision a time when visitors to the city will pick up a brochure that leads them on a tour of a revitalized harbor district complete with a micro-brewery/restaurant serving the Sound's world-famous oysters and other local food products, a beautifully landscaped park and ocean trail adjacent to a Long Wharf composting facility, and a mini-aquarium and science center that is the only example of symbiosis between an East Coast power plant and a combined aquaculture and aquaponics operation.

REFERENCES

Alexander, Kathy. Connecticut Department of Environmental Protection. Personal communication. April 2, 2001.

Connecticut Department of Environmental Protection (DEP). November 2000. New Project to Promote Recycling of Food Scraps in Connecticut.

Drummond, Kira, Michelle Garland, Brian O'Malley and Nam Jin Zeon. 1998. Efficacy of Industrial Symbiosis for Food Residues in the Greater New Haven Area. Prepared for F&ES 501: Industrial Ecology, Yale School of Forestry & Environmental Studies. (included in this volume).

Dunn and Bradstreet Company. 2001. *Dunn and Bradstreet Report, 2001.*

EcoRecycle Victoria. 1999. Waste Wise Training in the Food Processing Industry. http://www.ecorecycle.vic.gov.au. Accessed April 15, 2001.

EcoRecycle Victoria. 2000. Green Waste Action Plan. http://www.ecorecycle.vic.gov.au. Accessed April 22, 2001.

Elser, Rick. Former partner in Elm City Brewing. Personal communication, April 11, 2001.

Gadwa, Sigrun. May 1995. New Haven Oysters. Prepared for the Quinnipiac River Watershed Association. Unpublished.

Gertler, Nicholas. May 1995. Industrial Ecosystems: Developing Sustainable Industrial Structures. MIT Master's Thesis.

Global Aquatics. 1998. The S-92 Sequential System. http://www.growfish.com/s-92.htm. Accessed April 11, 2001.

Global Aquatics. Aquaponics.http://www.growfish.com/agua-ponics.htm. Accessed April 20, 2001.

Gongales, Jaime. Chabaso Bakery. Personal communication. April 4, 2001.

Heumann, J. February 1998. Recycling Facility of the Month: Trash to Art. *Waste Age.*

Housatonic Valley Association (HVA). January 1991. Municipal Solid Waste Composting: A Viable Disposal Option for Connecticut?

Industrial Economics, Inc. (IEc) November 1998. Anchoring the Loop: A Guide to Incorporating Municipal Recycling and Related Facilities into Eco-Industrial Networks. Unpublished Draft Report Prepared for U.S. EPA.

Kane, Hal. July/August 1997. Eco-Farming in Fiji. *World Watch.*
Klee, Rob. February 1999. Zero Waste System in Paradise. *BioCycle* 40(2).
Malloy, M. November 1997. Recycling Facility of the Month – One Million Served: Rhode Island's Recycling Facility, *Waste Age.*
May, C.J. April 11, 2001.Yale University Recycling Coordinator. Personal communication.
Parker, Nick, et al., Integrated Aquaculture based on *spirulina,* livestock wastes, brine, and power plant byproducts, Technical article T-9-615 of the College of Agricultural Sciences, Texas Tech University http://www.teru.ttu.edu/tcru/kc/pubs/parker/-p8O.htm Accessed April 11, 2001.
Research Triangle Institute. Eco-Industrial Parks: A Case Study and Analysis of Economic, Environmental, Technical, and Regulatory Issues, http://www.rti.ory/units/ssid/cer/parks.cfm. Accessed March 28, 2001.
Richmond, A., ed. 1986. CRC Handbook of Microalgal Mass Culture. Boca Raton: CRC Press.
U.S. Department of Commerce. 1997. Census of Manufacturer.
U.S. Environmental Protection Agency (EPA). May 1998. Organic Materials Management Strategies.
Tellus Institute, NYC. October 1990. Source Separation Composting Report (Draft).
Vanacore, Jr., Joseph. April 16, 2001. Personal communication.
White, K. August 1992. MRF of the Month – The Newington, Virginia Recyclery. *Waste Age.*
Zero Emissions Research and Initiatives (ZERI). 2001. Beer Bakes Bread, http://www.zeri.org/exl)o/prj beer.htm. Accessed March 22, 2001.
Zero Emissions Research and Initiatives (ZERI). 2000. The ZERI Brewery http://www.zeri.org/systems/brew.htm. Accessed August 18, 2000.
ZERI – Germany. October 1998. Field Trip to the Tunweni Brewery. http://www.zeroemission.de/brewerv/traveltsumebbrewery.htm. Accessed April 8, 2001.

ISSUE-SPECIFIC CONTACTS AND INFORMATION SOURCES

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APPENDIX

Why Waste Food? (WWF)

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Why Waste Food? is an ecologically-friendly community-based program aimed at minimizing the total amount of organic refuse from Yale's residential college dining halls.

Goals

- To reduce the amount of food wasted in the university dining halls through increased awareness and friendly inter-college competition;
- To encourage sensible eating habits while raising awareness about wasted food; and
- To unite students, faculty, and staff in reducing the amount of food waste.

Logistical Concerns

Each of the twelve residential colleges of Yale (Morse, Davenport, etc.) will need the following materials to participate:

- A large plastic barrel in which to collect table waste;
- A scale to measure the total amount of organic refuse, or ORT;
- An undergraduate student willing to oversee the project, which entails ensuring that all waste is properly sorted (napkins and other paper goods in one bin, food waste in another), weighing the ORT bucket at the end of each meal (or whichever meals are part of the contest), and encouraging college participation while setting an example for others to follow; and
- A member of the dining hall staff to work in conjunction with the undergraduate, boost publicity among workers, and give an accurate count of diners at each meal.

ORT is defined as all food on a given tray that is uneaten, not including bones, peels, plastics, paper products, soft drinks, juices, or coffee. Liquids would needlessly contribute to the total weight and should be discarded, with the exception of milk, which has nutritional value as re-usable organic material. This project requires a strict definition of ORT, and each participating college must abide by the same standard when measuring wasted food.

How Waste is Measured

The total amount of food waste, in units of mass, will be divided by the total number of diners at a given meal (students, faculty, and other guests eating in a college). Adding the three values (or less, depending on the total number of official meals) provides the waste per person (WPP) for the day. It is extremely important that each college knows which meals count towards the competition to keep things fair.

Who Wins?

The residential college with the least amount of food waste per person per week will receive a reward for its efforts. This could be a monetary sum much like the $100 given to the winner of the *Green Cup*, a weekly recycling competition among Yale's residential colleges. The competitive aspect of the WWF program, though not directly tied to the ideals of conservation, must not be underestimated. In order for the program to function effectively, the college consuming most efficiently ought to be recognized consistently for its efforts.

Who Else Wins?

It is my belief that EVERYONE WINS, including:

- Aramark, Inc., the food-service corporation in the dining halls. By observing the (hopefully) downward trend in wasted food resulting from the WWF program, Aramark can effectively reduce the total amount of food it purchases. The economic concepts of cost minimization, profit maximization, and material efficiency are invaluable aspects of WWF and any other successful environmental endeavor.
- The students: Not only will they be able to earn the weekly prize of $100 (or whatever prize is agreed upon), but students will also be participating in a program that can provide important social and environmental lessons. Of course, there are students who care little for philanthropy, and many of these may feel that they (or their parents) have purchased the right to waste food. As the director of this project, I fully expect to hear a lot of questions like "Why should I limit my food waste if I'm paying $12 for a meal?" or "The food is so expensive, why should I participate in a project that may limit what I'm paying for?" Some heartless Yalies may say, "I don't care about the needy. If there's nothing in it for me, why should I consider WWF?" Socially concerned students may have doubts as well, asking questions such as "How will this program directly help the homeless?" or "The company (Aramark) will be cooking the same amount of food regardless of how much of it we eat, so how would this project be effective?"

If WWF attains the goal of less waste, this has multiple positive consequences for everyone:

- Aramark – By lowering the amount of wasted food, conceivably Aramark could eventually lower its total food output per week and maintain or improve its food quality while keeping prices fixed, or perhaps lowering them.
- Yale diners – People would see the results in better tasting food, possibly more choices, and the chance to win a weekly prize for their college. Plus, Yale students concerned with the homeless and economic sustainability in general would presumably be willing to support the program based on its philanthropic merits.
- Yale University – The university could use this program as an example of environmental/social justice measures it encourages.

Industrial Symbiosis in New Haven Harbor: English Station West 2001

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ABSTRACT
Industrial ecology recognizes the importance of technology in our lives and seeks to reconcile it with the equally important need to minimize our damage to the environment. Its practitioners apply models of efficiency and reuse that can be found in natural ecosystems to the workings of industry. This project represents the application of these principals to the industrial region west of New Haven's English Station, a power plant that is currently closed but under consideration for reopening. The goal of our project was to examine and understand current material and energy flows in this area and to suggest possible material, water, or energy exchanges between existing industries. In addition, we sought to use the principles of industrial ecology to develop new economic plans for New Haven's waterfront area.

INTRODUCTION TO ENGLISH STATION AND AREA

Quinnipiac Energy is in the process of applying for operating permits from Connecticut's Department of Environmental Protection (DEP) to reopen English Station, a power plant dating to the 19th century that was decommissioned in the early 1990's. Should the permits be approved, the English Station power plant will begin to burn oil on a limited basis before replacing its current boilers with natural gas-fired combined cycle units after approximately two to three years.

Currently, the City of New Haven's economic development efforts are centered on expanding the tax base by putting vacant properties into use and on increasing employment opportunities for New Haven residents (Gilvarg 2001). We propose using the capacity for steam sharing in the area west of English Station and creating recycling centers for paper, plastics, metal, and glass, as well as for bulky wastes, to help encourage other small and medium-sized businesses to relocate to the area. English Station and the suggested recycling facilities will help make businesses more viable by providing them with wholesale electricity and access to inexpensive raw materials. These businesses would in turn provide the city with jobs and tax revenue, as well as adding further life to an industrial area with a rich history.

The area of New Haven included in this project, nestled between the Mill River and Interstate 91, is set apart from the neighborhoods on either side of it both by the physical boundaries and by its character (see Figure 1). Though this little strip is completely industrial and commercial, the neighborhoods across the river and highway are mainly residential. Historically, the area west of English Station was a part of the Wooster Square neighborhood of New Haven, which lies on the other side of Interstate 91. Recently, however, English Station has been of more concern to the residents of the Fair Haven neighborhood of New Haven, to the east, and is often included in plans for the neighborhood. Because the re-lighting of English Station and the status of industries near the Station will effect residents of both Wooster Square and Fair Haven, at least some knowledge of the development of these two neighborhoods is important.

Although the area west of English Station has historically been a center of industry in New Haven, it developed relatively late. Wooster Square Park was built in 1825, and many of New Haven's wealthier citizens built their homes around it. During the middle of the 19th century, numerous industries developed in the Wooster Square neighborhood. The eastern and southern edges of the neighborhood became home to the carriage-making, garment, and hardware industries, as well as to several other manufacturing outfits. In addition to the wealthier families who lived around the park, Wooster Square became home to Irish, and later Italian, immigrants who came to New Haven to work in the factories and lived in crowded tenements to the east of the park (Harrison 1995).

During the first 50 years of the 20th century, the neighborhood went into decline. Many factories shut down under the economic pressures of the Depression, and suburbanization led many of the middle class residents of the neighborhoods to move out to East Haven and other areas. Many of the industrial and residential buildings began to deteriorate. In 1951, the neighborhood was slated for redevelopment, although no work began until 1955 when Mayor Richard C. Lee secured national redevelopment funds for the area. Around the same time, Interstates 91 and 95 were constructed along the western and southern sides of the neighborhood, cutting the residential area off from the industrial areas bordering it. Around the park, the city carried out a successful revitalization effort that succeeded in turning Wooster Square into one of the city's nicest neighborhoods (Garvin 1996). Throughout these dramatic changes to the neighborhood, it has remained the center of the Italian community in New Haven. It contains numerous Italian restaurants and bakeries, as well as St. Michael's Catholic Church and the St. Paul/St. James Episcopal Church. Wooster Square hosts a number of seasonal and religious festivals during the summer.

On the other side of the Mill River, Fair Haven has a quite different history. Most of Fair Haven remained undeveloped farmland until the 1850s. Fishing and oystering were the key economic activities throughout the 19th century in spite of the development of other industries. During the latter half of the 19th century, the area between the Mill and Quinnipiac Rivers was home to several ship-building operations and a red sandstone quarry that supplied building materials for many New Haven construction projects (Townsend 1976).

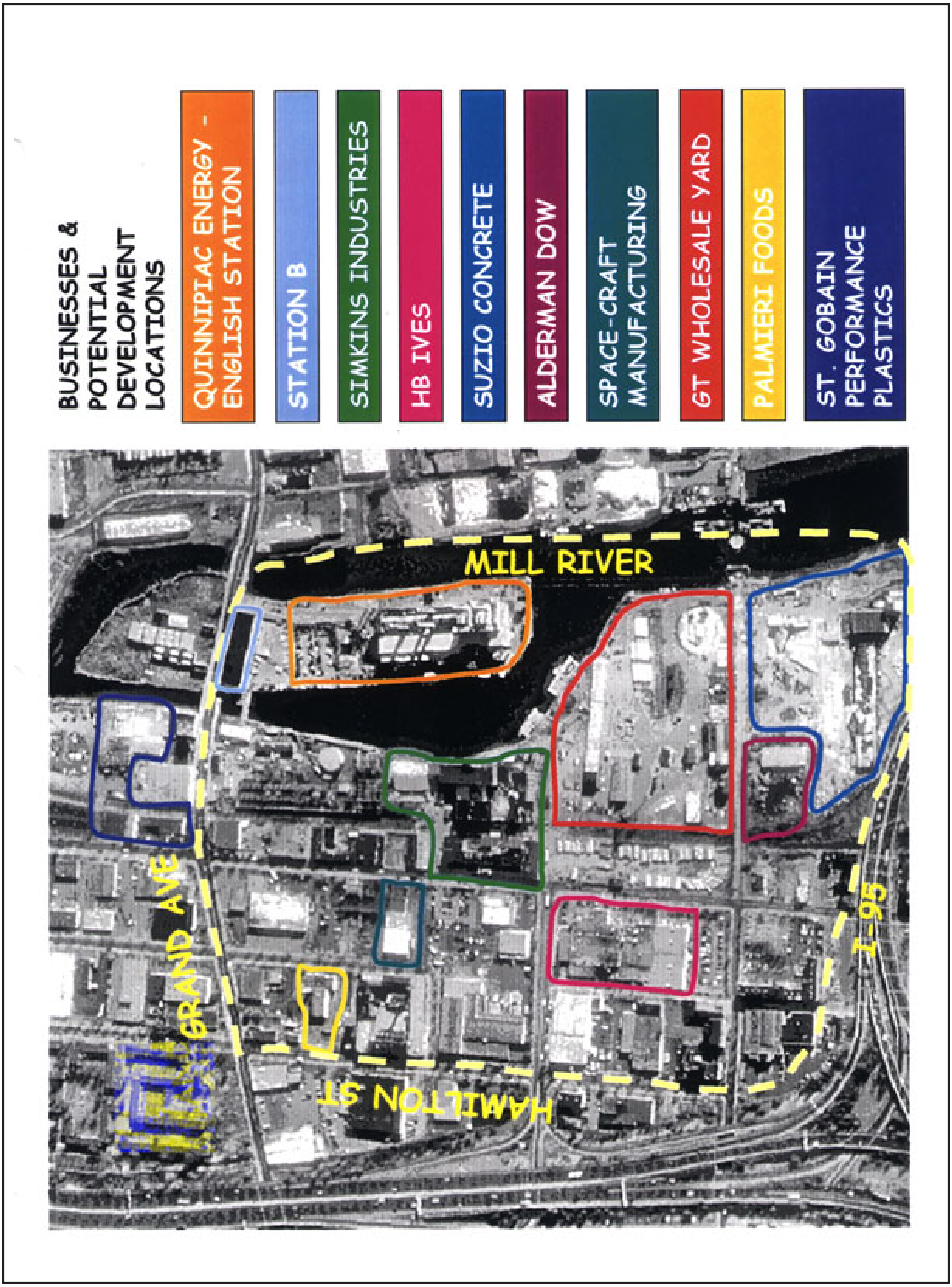

Figure 1 Aerial map of region with industries outlined

Residential development began seriously around the same time. Wooster Square was becoming overcrowded and more housing was needed for the city's growing industrial workforce. In addition, during the second half of the 19th century, several waves of immigration brought Irish, Germans, Poles, Russian Jews, and, finally, Italians to live and work in the area. A railway running between Fair Haven and downtown made the area attractive to both new industry and residential developers (Townsend 1976).

Like Wooster Square, Fair Haven experienced a decline during the latter half of the 20th century. Many middle class families moved out, leaving their houses to become blighted. Although today Fair Haven is one of New Haven's poorer neighborhoods, it has several dedicated citizens' groups working to revitalize the neighborhood. Since its earliest days, Grand Avenue has served as the main street in the Fair Haven neighborhood, and today is a thriving commercial district and the center of Latino life in the city.

The industrial history of Fair Haven is long and varied. One of the largest and most important firms to make its home there was the Sargent Company, which moved to New Haven in 1864 and occupied a huge, castle-like red-brick building on Water Street, between Wallace and Collis streets. Sargent manufactured a wide variety of hardware products, including hooks, door latches, cow bells, hammers, and other small items. By 1902, Sargent employed over 2,500 workers, and was one of the largest companies in New England and one of the nation's leading hardware manufacturers (Gillette 1982). Sargent moved to Long Wharf during the 1970s and its old building was demolished.

Although manufacturing has been in decline in northern U.S. cities for half a century, it should not be counted out as a possible factor in the economic development of New Haven. Today, about 10% of the jobs in New Haven are in manufacturing.

Besides Sargent, Fair Haven had several other large industries. C. Cowles and Company, which specialized in carriage parts, was founded in 1837 on Water Street. During the beginning of the 20th century, Cowles converted to producing hardware for automobiles, and is still in operation today as a hardware manufacturer. Water Street was also home to the (famous) New Haven Clock Company, founded by Hiram Camp in 1850. River Street housed the Bigelow Company, which produced machinery for gold mines, oil wells, and sugar plantations during the industrial expansion of the Gilded Age and, later, boilers. In 1880 the National Pipe Bending Company was established next door to Bigelow. The Connecticut Adamant Plaster Company opened on River Street in 1890 and turned gypsum into wall plaster there until it closed in 1935 (Beal 1951).

Although manufacturing has been in decline in northern U.S. cities for half a century, it should not be counted out as a possible factor in the economic development of New Haven. Today, about 10% of the jobs in New Haven are in manufacturing. More than 5,000 New Haven residents, and 15,000 or more residents of the surrounding area, are employed in manufacturing in New Haven (Connecticut Labor Department 1999). The City's Office of Business Development offers both loan programs and tax incentives that can be used to help businesses, including manufacturing firms, locate in New Haven (City of New Haven 2001).

EXISTING INDUSTRIES IN THE ENGLISH STATION WEST AREA

For the purposes of our project, the boundaries of the area being discussed are Grand Avenue to the north, the Mill River to the East, Interstate 95 to the south, and Hamilton Street to the west (see Figure 1). Below we have provided a brief overview of the nine companies located in and adjacent to the neighborhood that we consider in our analysis.

Quinnipiac Energy – English Station

English Station was once a United Illuminating power plant, which closed in 1992. It was recently purchased by Quinnipiac Energy and is currently slated for re-start. The proposal to operate units at this facility again has been controversial. Local residents, particularly those in the Fair Haven community, have opposed the re-start of the power plant, citing health concerns related to the potential increase in air pollution because of the plant's emissions. Currently, Quinnipiac Energy is moving forward in the Connecticut Department of Environmental Protection's air permitting process. The DEP Commissioner recently issued a tentative determination, and a public hearing on the permitting issue will likely be held within a few months of the time of this writing.

Figure 2 English Station

Quinnipiac Energy's plans for re-powering the site are split into three main phases:

1. Obtain a permit to operate from the CT DEP. If a permit is issued, operate the two existing boilers on 0.05% sulfur fuel. This fuel is much cleaner than the 1.0% sulfur fuel typically burned by large power plants in Connecticut. The draft DEP permit would also impose a fuel consumption limitation that in effect caps the total number of combined hours that the units can operate per year. The limit allows Quinnipiac

Energy to operate the two units for a combined total of roughly 561 hours per year at maximum firing rate (CT DEP 2001b).

2. Install four simple cycle turbine generators. These units would be primarily natural gas-fired, but would also likely be able to use diesel fuel as a backup (Mannis 2001).
3. Replace the two existing boilers with two combined-cycle technology units. Like the simple cycle units, these units would be primarily natural gas-fired, but would likely be able to use diesel fuel as a backup. A diagram describing combined cycle appears in Figure 3 (Mannis 2001, Holzman 2001).

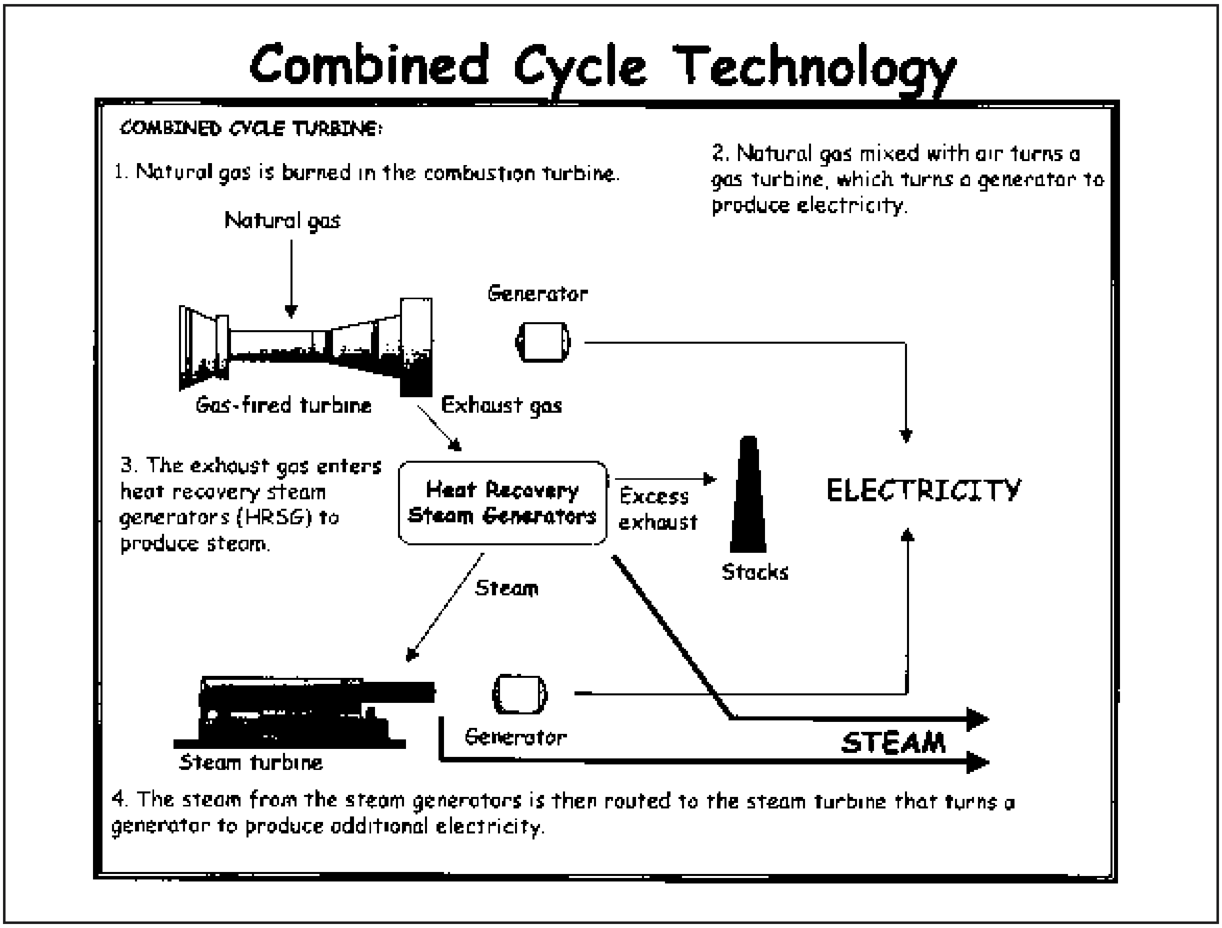

Figure 3 Combined Cycle Technology

Quinnipiac Energy – Station B

Station B is a large vacant building located on the northern part of the Quinnipiac Energy – English Station property. Quinnipiac Energy is looking for a tenant that would be able to make use of steam and direct electricity

Figure 4 Station B

connections. An ideal tenant would also be a light industrial (low polluting) or commercial business that might be able to take advantage of barge transport of goods on the Mill River. Quinnipiac Energy has had discussions with a granite-carving company and has also considered an industrial laundry service and a bakery for the site (Mannis 2001).

Simkins Industries

Simkins produces about 250 tons of recycled paperboard per day. Paperboard is used for products such as cereal, tissue and packaging boxes. Of the materials Simkins uses to manufacture its paperboard, about 75% is post-consumer waste (newspapers) and about 25% is pre-consumer waste (for example, fast food bags with logo misprints). The paperboard is made by sandwiching three separate layers (back liner, filler, top liner) together, pressing out the excess moisture and applying corn starch during the drying process to prevent curling. Clay is used to obtain a glossy white finish. The paperboard is sold in rolls or cut into sheets and sent out for printing (CT DEP 2001a; Doucette 2001).

Simkins is able to recycle all scrap paper product from its process back into the manufacturing process. This is accomplished as follows:

- A water-paper sludge mixture passes through an in-house water screening and treatment center to separate the paper sludge from the water.
- The paper sludge is extracted and used to produce the filler layer of the paperboard.
- The treated water (150,000 to 250,000 gallons per day) is discharged to the public sewer system, where it is then carried to the City of New Haven's treatment center (Doucette 2001).

Simkins must ship off-site approximately 100 to 110 tons of miscellaneous wastes per month. These wastes are contaminants found in the baled recycled materials brought in for processing and include metal cans, plastics, and Styrofoam (Doucette 2001).

Simkins' largest source of air pollution is a Bigelow boiler used to generate steam for both the paper process and to power a 3.5 MW generator. This generator provides Simkins with roughly half its electricity needs. The Bigelow boiler can be fired on either natural gas or oil, with the choice of fuel determined primarily by cost.

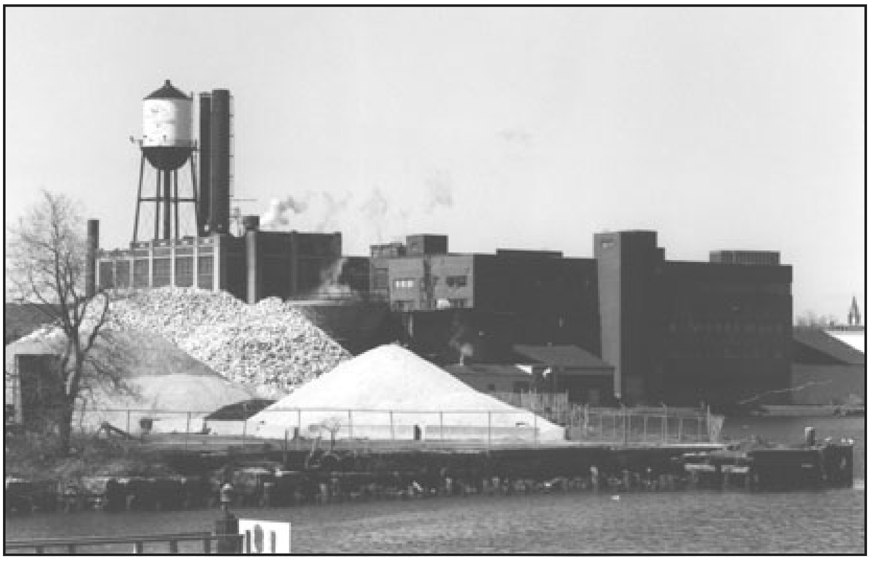

Figure 5 Simkins Industries (background) and GT Wholesale Yard (foreground)

GT (Gateway Terminal) Wholesale Yard

This company purchases bulk materials and resells them. Gateway unloads, stores, sells, and delivers salt, sand, coal stone, cobblestone, landscaping materials, and sometimes firewood. There is no manufacturing done on-site. The wholesale yard is located on a large tract of land adjacent to the Mill River. Potentially, some of this space could be used as a bulky/construction waste recycling site. Its location along the river would make barge transport of the wastes a possibility (Dubno 2001).

HB Ives

HB Ives plates base metal pieces of architectural hardware, such as bathroom fixtures and cabinet handles, with chrome, copper, and nickel. Ives used to have a foundry on-site to manufacture the various pieces of architectural hardware but this process was recently shut down. Ives now purchases the already formed metal pieces and plates them in one of its metal-plating lines. Some of the pieces are also finished in a clear lacquer line (CT DEP 1998).

When the company periodically empties tanks in its plating lines, the water-based metal plating solutions are handled as follows:

- The water-based solutions pass through an in-house water treatment center to separate the metal components from the water.
- The metal sludge is then shipped as hazardous waste to a metal reclamation facility in Pennsylvania.
- The treated water (about 62,000 gallons per day) is discharged to the public sewer system, where it is then carried to the City of New Haven's treatment center (Kleinbaum 2001).

Figure 6 HB Ives

Since HB Ives eliminated the foundry portion of its business, it has significantly reduced the amount of waste metal it produces. Still, the company sends about 850,000 pounds per year of scrap metal off site. Ives used to sell its scrap metal to Alderman Dow, but now sells to a dealer based in Bristol, Connecticut for a better price (Kleinbaum 2001).

Space-Craft Manufacturing

Space-Craft Manufacturing machines aerospace components of aircraft engines for companies such as Pratt & Whitney and General Electric. It orders already-forged metal from an out-of-state source and manufactures engine rings from high temperature alloys (composed primarily of nickel). The facility's primary process is manufacturing parts using a vertical turret lathe that runs on electrical energy. This machining process uses a water-soluble coolant. Process water currently comes from the tap and is reused. When not in use, the water is stored in a holding tank. Leftover oil from the machining process is recycled. No other chemicals come out of Space-Craft's processes. Metal chip scraps are sent to Alderman Dow (Clark 2001).

Figure 7 Space-Craft Manufacturing

Alderman Dow

Alderman Dow buys and resells scrap metals of all kinds. It has relationships with several hundred businesses, including many local firms. Though it will buy scrap metal in any amount, it usually sells in quantities of 20,000 to 40,000 pounds. Several million tons of metal pass through the scrap yard every year but, because Alderman Dow does not alter it, the company has no significant waste streams (Alderman 2001).

Figure 8 Alderman Dow

L. Suzio Concrete Company

The L. Suzio Concrete Company is a ready-mix concrete batching plant that produces concrete from natural sand, crushed rock, cement, and various chemicals. It produces about 116,000 cubic yards of concrete per year. Suzio carries its mixed concrete in trucks to construction sites. Leftover concrete from the job site is run through a washout plant to separate out the components. Sand and stone are sold as materials for road base, while the cement putty is sold for use in filling or capping landfills (Suzio 2001).

Figure 9 L. Suzio Concrete Company

Saint-Gobain Performance Plastics

Saint-Gobain Performance Plastics (formerly Furon, formerly CHR) manufactures pressure-sensitive tapes on six adhesive coating machines and silicone-based sponge and sheet rubber on four presses. A contact at Saint-Gobain stated that very little plastic residue is created at the facility. While this company is located north of Grand Avenue and thus outside our neighborhood, it was still considered in our analysis for reasons to be clarified later in this paper (Oszurak 2001; CT DEP 1997).

Figure 10 Saint-Gobain Performance Plastics

Palmieri Food Products

Palmieri Food Products produces and packages food products such as tomato sauces. It temporarily stores sauces in large metal barrels, which it sells used to Alderman Dow (Alderman 2001).

Figure 11 Palmieri Food Products

TARGET ISSUES

Our team identified steam sharing, the creation of a paper, plastics, metal, and glass recycling facility, and the creation of a bulky waste recycling facility as our target issues. While each of these topics has a short, intermediate, and long-term development phase, we have integrated the discussion of these phases throughout the text.

Why do our recommendations focus on the creation of new industries as opposed to creating links between those already existing? As noted in our Overview of Existing Industries, several companies in this region are already involved in material exchanges – for example, both Space-Craft Manufacturing and Palmieri Foods send their scrap metal to Alderman Dow. Other industries in this region simply do not have significant waste streams because most of the materials they handle are pre-manufactured elsewhere, such as Space-Craft's and HB Ives' metal base pieces and Palmieri's metal barrels. Some industries already reuse materials and scrap in-house, as is the case with Simkins' paper pulp and Suzio's concrete mix.

In some cases, a company has specific requirements for inputs that limit its ability to exchange materials. Suzio, for example, is a large consumer of water. Our team initially proposed the use of brown water in the concrete mixing process. However, Suzio requires water that is fairly pure and of a consistent pH (Suzio 2001a). None of the existing companies currently have waste water pure enough for Suzio to use. However, there are still possibilities for future water-sharing arrangements. Some industrial cleaners discharge large amounts of pH neutral water that might be usable by Suzio or Simkins, and Simkins' waste water could be processed to make it reusable by Suzio. Overall, though, we did not feel that water-sharing was significant enough to include as a target area.

Our team also faced unexpected feasibility issues when considering bringing in new industries. A particular example involves a tile manufacturer. Our team noticed an unusual number of tile retailers in our area, and we discovered that some tile manufacturers make a product that uses concrete. Given the nearby location of Suzio, we identified a tile manufacturer as a good potential match for the region. We learned from the manager of New Haven's Standard Tile that, for a variety of reasons, tile is almost never manufactured in the United States (Douglas 2001).

Working within these limitations, our team has made recommendations for new industries that will fit with the kinds of material flows already present in the area.

Steam Sharing

One of the key areas of potential symbiosis in our target area is steam sharing. Incorporation of this practice hinges on Quinnipiac Energy's replacement of its two current oil-fired boilers with two natural gas-fired combined cycle units. As its name suggests, combined cycle technology generates electricity at two points in its cycle. A diagram of this technology can be found in Figure 3 (Holzman 2001).

One of the key areas of potential symbiosis in our target area is steam sharing. Incorporation of this practice hinges on Quinnipiac Energy's replacement of its two current oil-fired boilers with two natural gas-fired combined cycle units.

The first source of electricity is a generator that is turned by the gas-fired turbine as gas is combusted in the turbine. Hot exhaust gas from the gas turbine then enters a heat recovery steam generator (HRSG). In the HRSG, the hot air is used to convert water to steam. This steam is piped to a steam turbine that uses the steam to turn a shaft connected to a second electricity generator. In a closed-loop system, the degraded steam would then be returned to the HRSG for re-heating.

In a steam-sharing scenario, steam can be piped to a neighboring building or industry. The steam can either be drawn directly from the HRSG or at a point after it has passed through the steam turbine. The neighboring building can use the steam for industrial processes and/or for heating and cooling purposes. Because hot water still contains energy that can be useful (i.e., less energy is needed to bring hot water or low-quality steam back to high-quality steam), the spent steam and condensate might then be piped back to the HRSG.

Again, this potential use of steam sharing depends on the installation of natural gas-fired combined technology at English Station. Such a technology conversion would likely not occur any sooner than two years from the time of this writing. Once Quinnipiac Energy has received approval to operate the new units on a full-time basis, it would likely begin connecting steam pipelines to neighboring buildings and industries. Initial users of the steam would include the tenant of Station B and Simkins Industries. The piping to Simkins from English Station would most likely go out to Grand Avenue, over the bridge and back down along the Mill River to Simkins. Although this requires more piping than would a plan to connect English Station and Simkins through direct piping buried under the Mill River, it would be the less expensive option according to David Damer, a former United Illuminated employee (Damer 2001).

Steam sharing could help minimize overall air emissions increases in the area, and significantly decrease the amount of sulfur dioxide (SO_2) emitted.

As stated previously, the potential re-start of English Station has inspired opposition, especially from those in the nearby Fair Haven community concerned about increased air pollution levels. Steam sharing could help minimize overall air emissions increases in the area, and significantly decrease the amount of sulfur dioxide (SO_2) emitted. For example, if Simkins were able to connect to English Station's steam and buy its electricity wholesale from the power plant, it could shut down the Bigelow boiler it is currently using to create steam and electricity. The environmental benefits from such an arrangement are summarized in Table 1.

Many industrial cleaners also burn their own fuel to create steam for drying clothes and linens. Quinnipiac Energy has been considering an industrial cleaner as a potential occupant of Station B. Pipes could easily be installed from English Station to Station B, allowing a cleaner to replace its own boiler with electricity and steam from the power plant. Industrial cleaners can be relatively clean commercial businesses. Because they use high-temperature water, they require fewer cleaning chemicals per gallon of water than individual users or small laundry services. The water they discharge can also be pH neutral.

Table 1 Emissions Projections with Closing of Bigelow Boiler

	NOx (tons per year)	SO_2 (tons per year)	PM10 (tons per year)
English Station (on natural gas)			
2 combined cycle units	60.4	4.8	90.2
4 simple cycle units	75.6	6.0	112.8
projected total emissions on gas	+136.0	+10.8	+203.0
Simkins' projected reductions (based on average of 1999/2000 emissions)	-93.2	-400.2	-26.8

(Source: Holzman 2001, CT DEP emissions statements)

A good-sized industrial cleaner that handles around 1,500 pounds of clothes and linens a day would employ 30 to 40 people (Johnston 2001).

After the initial steam connections to Station B and Simkins Industries are completed, further connections to additional industries in the area should be considered. Contacts at both HB Ives and St. Gobain Performance Plastics indicated that their companies would be interested in a steam-sharing relationship with English Station (Kleinbaum 2001; Oszurak 2001). Longer-term plans could include using the steam to heat and cool nearby housing complexes. While replacing infrastructure in existing complexes might prove to be too costly, any new developments in the area should definitely be planned with the steam connection in mind.

Interestingly, this is not the first time that English Station has been considered as part of a steam-sharing arrangement. In the late 1970s, an arrangement with Simkins was considered. Around this same time, the usage pattern of English Station changed from base-loaded units (operating most of the time) to peaking units (operating only during peak demand days during the summer and winter). Peaking units would not have operated enough to provide Simkins with its steam demand, and thus the plans were shelved (Damer 2001).

In the early 1990s, the steam sharing idea was considered again, this time involving the Yale University steam system. To accomplish this, English Station would have had to convert its units to combined cycle units at that time. Due to various reasons outside the scope of this study, that plan was never implemented and the steam-sharing concept was put on hold again (Damer 2001).

Creation of a Plastics, Paper, Metal and Glass (PPMG) Recycling Facility

Recycling is one of the key points of industrial ecology. There are all kinds of recyclable materials in an industrial community, including everything from glass jars to batteries. A recycling center is a beneficial facility for any eco-industrial park. One of the goals of this project is to bring a facility capable of sorting, baling, and re-selling recyclable materials to the area. Currently, the City of New Haven's Department of Public Works operates a waste transfer center on Middletown Avenue that collects glass, plastic, paper, and metal cans from New Haven, Yale, and several neighboring towns. At the moment, the transfer station serves only as a collection point, and the recyclables are sold to Willimantic Waste, a facility in Stratford, Connecticut that sorts the materials and sells them to end users (Mason 2001). The recycling coordinators for both Yale and the City of New Haven agree that it would be beneficial for the city to have a business in New Haven that can sort and sell the plastic, paper, glass, and metal collected by the city and by Yale (May 2001; Mason 2001). Depending on its capacity, the facility might be able to handle materials from other municipalities as well.

Such a facility would require approximately 50,000 square feet, or four acres, of space. During the 1980s, Hershman Recycling, which is now located in Stratford, operated this kind of facility on Chapel and East Streets (Anderson 2001). It would be possible to establish a recycling center within the English Station West area, but it would involve either tearing down existing vacant buildings or purchasing land from the GT Wholesale Yard on East and Chapel. This area is heavily built up and though there are currently many vacant buildings, there is little clear space.

Having a recycling center in New Haven would facilitate the development of industries that utilize recycled materials. A mid-term goal of this project is to encourage a relationship between the recycling center and Simkins, a boxboard manufacturer. In addition, it might be possible for Alderman Dow to purchase crushed steel or aluminum cans from the center if they were sorted correctly.

The facility would require both outdoor and indoor space. Recycling trucks would dump mixed glass, plastic, paper, and metal onto a tipping floor. From there, papers would be taken out, sorted, baled, and sent directly to market. Machines would load the remaining materials onto a conveyor belt to take them past a processing line, where employees would sort metal, glass, and plastic into separate containers. Once sorted, plastic and metal would be flattened and baled and glass is crushed and piled. A large recycling center could process 100 tons of materials per shift and employ around 30 people (Montgomery County 2001). In other cities, recycling centers have successfully taken part in welfare-to-work programs, and we recommend that any facility here be tied to an employment program. However it should be noted that having a recycling facility may create noise and safety concerns for the residential neighborhoods since recycling trucks will pass through on their way to and from the facility. The authors recommend that the City of New Haven look into these land and transportation issues in more detail if it decides to pursue this idea further.

Having a recycling center in New Haven would facilitate the development of industries that utilize recycled materials. A mid-term goal of this project is to encourage a relationship between the recycling center and Simkins, a boxboard manufacturer. In addition, it might be possible for Alderman Dow to purchase crushed steel or aluminum cans from the center if they were sorted correctly. In the longer term, we would suggest that the recycling facility be used to encourage a glassworks and a plastics company, both "clean" businesses, to locate in the area and take advantage of the raw materials that the recycling company can provide.

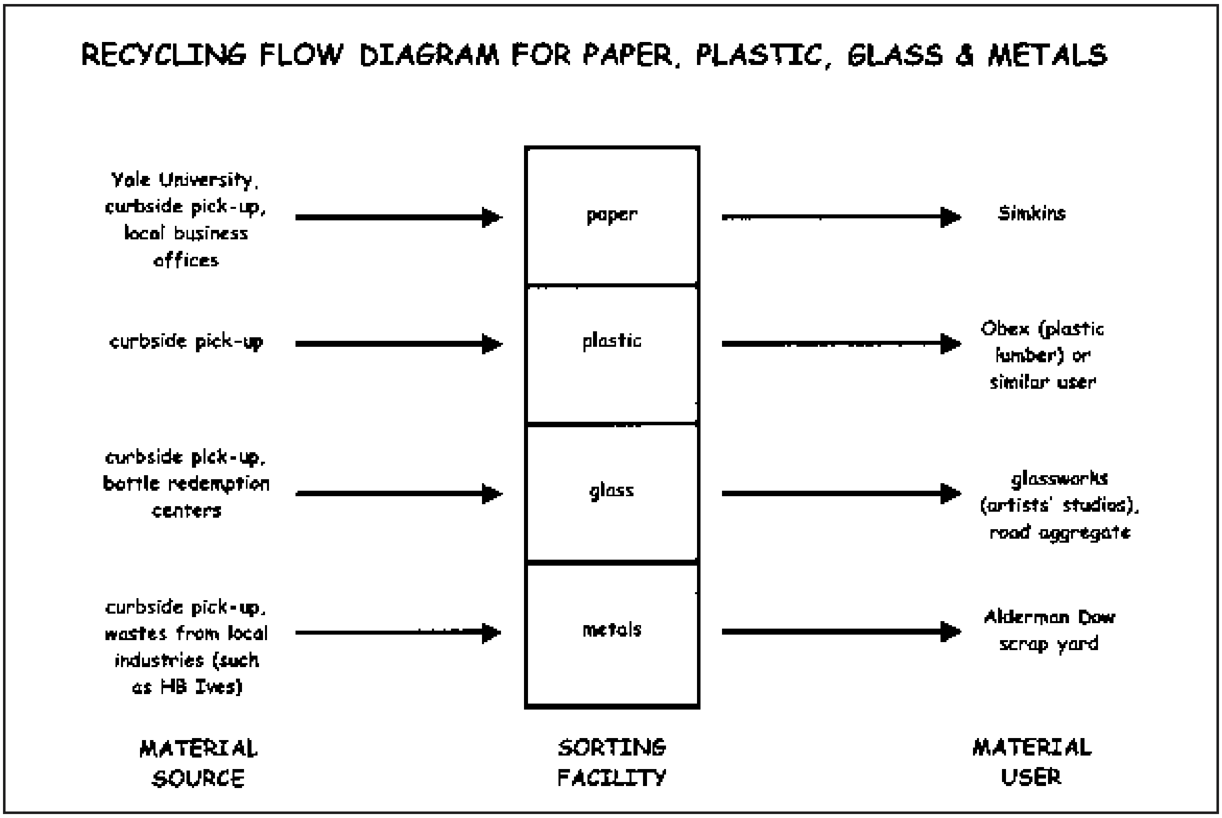

Figure 12 Recycling Flow Diagram for Paper, Plastic, Glass, and Metals

Recycling Paper

Simkins currently recycles paper that it purchases in bulk from publishing firms or other large paper users. Simkins could potentially use post-consumer paper collected locally if it were assured that the paper would be sorted correctly. In the past, Simkins has considered adding a paper sorting operation of its own to its factory, but never came to a satisfactory agreement with the city. A recycling facility located near Simkins could work with the boxboard manufacturer to supply it with locally collected paper in a usable form. Establishing such a relationship is a goal for the next three to five years.

Recycling Glass

One strong possibility for utilizing recycled glass is to bring in a glassworks facility or set up studios for independent glass artisans. There is currently a glut of recycled glass in the market, mostly of green and other colored glasses. Glassblowers that use colored glass could buy it very cheaply from the recycling facility, which could assure it a steady supply of materials (May 2001). Glass-blowing is also a relatively clean industry, since glassworks usually use natural gas-fired furnaces and produce no significant waste materials besides glass (Bittersweet Glass 2001).

Many commercial glassworks buy a mixture of sand and silica, which they melt down for use in their products. They often also have the capacity to re-melt their own leftover glass for reuse (Bittersweet Glass 2001). It should be fairly easy for a glassworks to increase the amount of recycling they do if a supply of inexpensive glass is readily available from a nearby recycling plant. In addition, there will already be natural gas pipelines in the area,which the glassworks can use to fuel their furnaces.

Either a small-to-medium sized glassworks or glass artisan studios would be a positive addition to Fair Haven. Showrooms facing the street would enhance the physical charm of the neighborhood and tours of the glassworks could be arranged for children from area schools, making the facilities a cultural asset as well. There are several empty buildings in the English Station West area that could easily be rehabilitated to house a small to moderately sized glassworks or colony of artist studios. The Halprin Building on East Street currently has 6,000 square feet of space and a dock for lease. It is a mixed-use building with several service and retail businesses already on the ground floor. There is a plumbing supply showroom and a screen printing business on either side, forming a buffer between the building and the heavier industries in the area.

Another possibility for recycled glass is for the recycling facility to work with a construction materials company to supply crushed glass for use in road construction. Connecticut's Proposed Solid Waste Management Plan specifically encourages the use of glass aggregate in highway construction.

Another possibility for recycled glass is for the recycling facility to work with a construction materials company to supply crushed glass for use in road construction. Connecticut's Proposed Solid Waste Management Plan specifically encourages the use of glass aggregate in highway construction.

Recycling Plastics

Bringing in a small plastics manufacturer to use recycled plastics collected locally is another long-term goal. The Obex plastic company has expressed interest in relocating to New Haven in the past. Obex produces a product called Novawood© out of 100% recycled plastic. It grinds recycled plastics and reforms them into a lumber-like product. This process does not change the molecular structure of the plastics, resulting in zero emissions, zero effluents, no chemical leachate, and a product that is non-toxic and inert. Obex makes Novawood© into outdoor tiles and other yard implements such as compost bins.

Though Obex currently purchases some post-consumer plastics, it relies mainly on large companies, such as Pitney-Bowes, to supply its plastic. Plastic collected from consumers is usually not clean or well-sorted enough to be usable for processing Novawood© (May 2001). By working with the recycling facility to clean and sort local plastics to the necessary degree, Obex might be able to use more post-consumer plastics.

Though the authors were unable to determine Obex's specific space needs, we believe there are facilities within the English Station West area that would be suitable for it, or a similar company. The Hamilton Industrial Center on Hamilton Street has a large amount of vacant space. Since a plastics company would probably operate during the daytime, and the club at night, the two would be unlikely to bother one another.

Creation of a Bulky Waste Recycling Facility

Based both on the State of Connecticut's recycling needs and the local availability of materials, we recommend the establishment of a bulky waste recycling facility in New Haven. Connecticut's Department of Environmental Protection (DEP) estimates that the state generates approximately 2 million tons/year of bulky and related wastes and that over 740,000 tons of this is construction and demolition waste from buildings. The state currently has only four permitted landfills that have enough capacity to accept bulky waste, and if all of the construction and demolition waste generated statewide is sent to these landfills their remaining capacity could be exhausted within one to two years. As the current Commissioner of DEP has stated, Connecticut will be facing "a crisis in bulky waste management" in just a few years. The DEP has identified the development of an infrastructure for recycling bulky wastes as one of the three most critical issues facing the state over the next five to ten years (State of Connecticut 1999). DEP is encouraging private entities to develop bulky waste processing and recycling capacity. It would also like to see the development of markets for the reuse of salvaged material (State of Connecticut 1999).

The DEP has identified the development of an infrastructure for recycling bulky wastes as one of the three most critical issues facing the state over the next five to ten years (State of Connecticut 1999).

This is powerful evidence for the need to develop new bulky waste recycling facilities in Connecticut. But why locate one near the area west of English Station? The primary reason is that this area will be the site of a number of major construction projects in the upcoming years, particularly because of its location near the junction of Interstate 95 and Interstate 91. This junction is scheduled to be reconfigured in 2006 (Connecticut Department of Transportation 2001). In addition, a major project to tear down and replace the Quinnipiac River Bridge is planned for 2003. These construction projects will create an enormous amount of local bulky wastes that the state simply does not have room to landfill. A bulky waste recycling facility would be able to process and recycle materials from construction and demolition projects. Our group proposes to establish a facility that would reduce volumes of waste, allow for the reuse of salvaged building materials, and process concrete and asphalt for reuse in road construction. These services are in line with DEP's own waste management plans (State of Connecticut 1999).

In the course of our research, our team became interested in a particular model provided by a California bulky waste recycling company. Raisch Products, a California-based recycling company, has developed an extensive recycling program that includes a Reuse/Recycling Ecological Park (Raisch Products 2001). The Ecological Park concept is a means of promoting recycling and reuse from cradle to grave by establishing links with waste producers all the way through to waste reusers. Company representatives work with the generators of waste as well as government agencies to reduce waste at the source. Waste that is produced is sorted by the Raisch facility, which is capable of handling up to 5,000 tons of material a day (Berry 2001). This sorting process includes commingled materials, such as rebar embedded in concrete. Materials that can be reused (such as brick, lumber, and tile) are then sent to a used-building materials warehouse to be sold to local residents and contractors (Raisch Products 2001). Materials that cannot be reused are directed to the appropriate recycler.

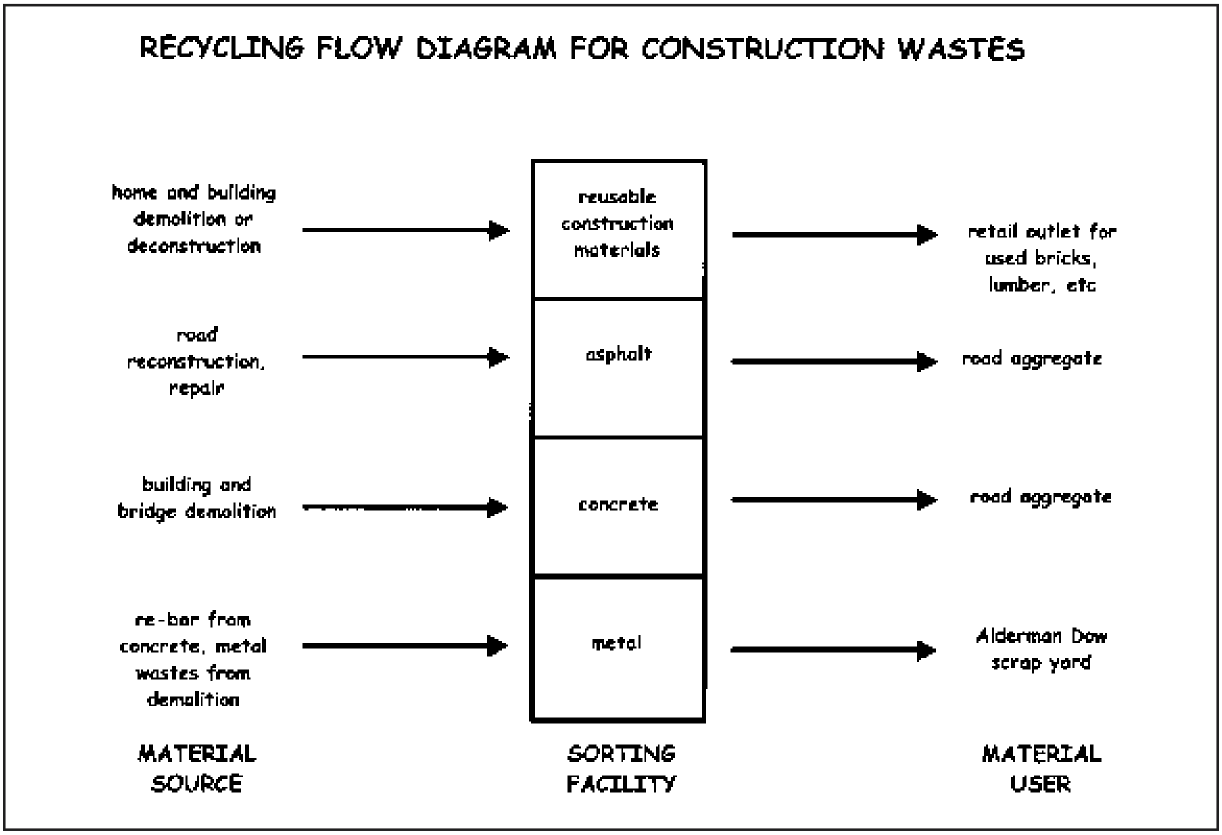

Figure 13 Recycling Flow Diagram for Construction Wastes

Raisch recycles all of its asphalt and concrete internally to create a new product (Berry 2001). The asphalt and concrete is processed into a base rock that meets the local transportation department's requirements for road construction. Thus a similar bulky waste recycling facility in New Haven might not only recycle demolition waste from the upcoming New Haven transportation project, but also provide the raw materials for new construction projects.

The Raisch Company is only one model, and there are other bulky waste recycling models here in Connecticut that are worth examining, such as Recycled Concrete Products in Hartford run by Don Mucci (Mucci 2001). Our preliminary research indicated, however, that Raisch exhibits unusually forward environmental thinking with its Ecological Park concept.

If a bulky waste recycling facility is to be brought to New Haven, several potentially limiting factors must be addressed. The first is a question of where to locate such a facility. A Raisch facility requires from three to five acres though a smaller operation could require less space (Berry 2001). In any case, the area west of English Station does not have sufficient unused land. As an alternative location, our team suggests potentially locating such a facility in the Long Wharf area. According to the student group researching Long Wharf, it has an excess of unused space including a number of unused parking lots (McEneaney 2001). Moreover, the Long Wharf group has proposed to tear up the asphalt in these parking lots. This would create an immediate source of material for the facility.

The safety concerns of local residents also need to be addressed if a bulky waste recycling facility is to come to New Haven. Residents may be concerned about particulate matter being released in the air. As co-chair of the Fair Haven Community Management Team, Lee Cruz has identified this issue as of utmost importance to Fair Haven residents, who suffer from unusually high rates of asthma (Cruz 2001). If the facility is located in the non-residential Long Wharf area, this may not prove to be a problem. In addition, a company may take measures to adequately reduce particulate. For instance, Raisch uses a "water blanket dust control system" to do just that (Berry 2001).

Cruz and members of the city's Department of Economic Development have indicated that creating employment opportunities in New Haven is a priority. Our team believes that a bulky waste recycling facility and a PPMG recycling facility would offer significant employment opportunities, particularly for those who have few job skills. Raisch, for example, offers both job training and placement and is committed to working with youths, troubled teens, drug and criminal rehabilitation programs, and welfare relief efforts where appropriate (Raisch Products 2001). Our team recommends the establishment of recycling facilities with a similar commitment to the surrounding community. The development of community employment programs is a long-term goal of this project, and the Recycling Task Force could greatly assist in this effort. Both of the recycling facilities, as well as any new glassworks, cleaners, or plastics companies that locate in New Haven, could be tied into existing Empowerment Zone initiatives, such as the customized job training program, the Construction Workforce Initiative, and the Summer Youth Employment Program (Empower New Haven 2000).

Before either a PPMG recycling facility or a bulky waste recycling facility can be brought to New Haven, a Recycling Task Force must be established. Such a task force would consist of city officials from DEP, the Department of Public Works, and the Department of Economic Development, executives of existing New Haven industries (particularly those with a capacity to use recycled materials), and local residents.

Creation of a Recycling Task Force

Before either a PPMG recycling facility or a bulky waste recycling facility can be brought to New Haven, a Recycling Task Force must be established. This should occur in the short-term development phase and its members should continue to meet through the intermediate and long-term phases. Such a task force would consist of city officials from DEP, the Department of Public Works, and the Department of Economic Development, executives of existing New Haven industries (particularly those with a capacity to use recycled materials), and local residents. The Recycling Task Force would investigate the possibility of increasing New Haven's capacity to recycle materials through existing means and through the introduction of new industries. The Task Force would address issues of feasibility, recruitment of new industries, and concerns of local citizens. It could also identify potential areas for industrial symbiosis between existing and incoming industries.

Such a Task Force is essential to New Haven if principles of Industrial Ecology are to begin to be applied to the city's industry. While the exchange of energy, waste, and water may be the long-term goal of any eco-industrial park, the sharing of information is an equally important goal if not the prerequisite for these other kinds of exchanges. A New Haven Recycling Task Force would represent the beginning of a commitment to industrial symbiotic relationships.

SUMMARY OF RECOMMENDATIONS

In order to create a useful set of recommendations, our team relied on the assistance and information provided by several existing New Haven industries. These include Quinnipiac Energy, Simkins Industries, HB Ives, L. Suzio Concrete Company , Alderman Dow Scrap Metal, Space-Craft Manufacturing, GT Wholesale Yard, Palmieri Food Products, and Saint-Gobain Performance Plastics. Much of the information in this paper comes from telephone interviews with company representatives. Some – such as our most up-to-date information from Quinnipiac Energy – comes from a site visit. Our team also contacted several companies in other cities and states in order to base our recommendations on ideas that have already proved feasible.

While a number of opportunities exist in our region for the application of industrial ecology, we have concentrated our efforts on three particularly promising issues:

- Steam usage/sharing;
- Creation of a glass, paper, aluminum, and plastics recycling facility;
- Creation of a bulky waste recycling facility.

Steam usage and sharing

Combined cycle technology could be configured at English Station to produce excess steam as a byproduct. Our team encourages local industries to view this steam as a primary or secondary source of energy as well as a way of reducing harmful air emissions.

Creation of a Recycling Facility

New Haven currently does not have a recycling facility that is capable of sorting and baling glass, paper, aluminum, and plastics. As a result, the City must send out such materials to a neighboring municipality. Our team recommends that these materials be viewed as a potentially valuable stream of raw materials. We propose that such materials be recycled within New Haven in order to be used by existing manufacturers and to attract new industries to the city.

Creation of a Bulky Waste Recycling Facility

The state of Connecticut is currently unprepared to manage the amount of bulky waste produced by ongoing construction and demolition projects. Our team recommends the creation of a bulky waste recycling facility in order to create a new product from used concrete and asphalt and to return used building materials to New Haven residents and businesses.

In addition, we recommend the establishment of a Recycling Task Force to facilitate communication among existing area businesses, city officials, and community members and to work towards making progress in the above-mentioned areas. Our recommendations are based on short-term (1-2 years), intermediate-term (3-5 years), and long-term (6-10 year) time frames. The following is a summary of our recommendations:

Short-term

- Start English Station power plant on low sulfur oil according to a plan that restricts the number of hours of operation per year.
- Transfer scrap metal from Ives to Alderman Dow.
- Create a Recycling Task Force.
- Convert English Station to natural gas-fired combined cycle units within a two to three year time frame.
- Lay steam pipeline from English Station to Simkins and Station B (the building adjacent to English Station) once conversion to natural gas-fired units commences.

Intermediate-Term

- Bring a tenant into Station B. Possible tenants include a granite cutter or industrial cleaner.
- Expand steam pipeline infrastructure to other local businesses.
- Establish a recycling center.
- Begin operation of the recycling center's paper unit.
- Locate a bulky waste recycling facility in the Long Wharf area.
- Develop artist studios in existing tenant buildings.

Long-term

- Expand steam pipeline to residential housing complexes.
- Begin operation of glass, plastics, and metal recycling at the recycling center.
- Create a retail warehouse for used-building materials.
- Bring glassblowers into artist studios.
- Bring in a recycled plastics manufacturer.
- Develop a community outreach and employment program through both recycling facilities.

Communication between existing and proposed industries and city officials will be essential to the future of this region. While our team has attempted to make feasible recommendations, all incoming industries will have to address a number of potentially limiting factors. The amount of available space may restrict the size and type of industries looking to locate in this area. New industries also must be assured of a significant source of raw materials and a market share large enough to keep their business sustainable. In addition, this geographical region borders on the mostly residential Fair Haven and Wooster Square communities. Residents of these communities rightfully have an interest in protecting their health and safety and the character of their neighborhoods. Any plans for economic development must be shared with the public.

In spite of these concerns, the region west of English Station holds great potential for the future of New Haven's economic and environmental success. Already, the region contains a number of manufacturers with significant material inputs and outputs. Moreover, our team found that many of these companies were already engaged in or exploring material exchanges where possible. Even where none were possible, many industry executives were still familiar with co-located businesses. Establishing communication between companies is perhaps the most difficult and important step toward creating opportunities for industrial symbiosis. With this in mind, the industrial region west of English Station can already be said to be moving in a positive direction.

ACKNOWLEDGEMENTS

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REFERENCES

Alderman, Jason. 2001. Alderman Dow. Telephone interviews. March 26, April 3.

Beal, Carleton. 1951. *Our Yankee Heritage.* Bradley & Scoville, Inc.: New Haven, CT.

Berry, Chuck. 2001. Raisch Products. Telephone interview. April 13.

Bittersweet Glass. 2001. Telephone interview.

City of New Haven. 2001. Programs Offered by the Office of Business Development. Online posting, http://www.cityofnewhaven.com/economic/eco3.htm.

Clark, Dan. 2001. Space-Craft Manufacturing. Telephone interview. April 2.

Connecticut Department of Environmental Protection (CT DEP). 1997. Premise Evaluation Report. prepared for Furon (now St. Gobain Performance Plastics), Mike LaFleur. May 9, 1997.

Connecticut Department of Environmental Protection (CT DEP). 1998. Premise Evaluation Report. prepared for HB Ives, Lou Santos. September 30, 1998.

Connecticut Department of Environmental Protection (CT DEP). 2001a. Premise Evaluation Report. prepared for Simkins Industries, Phil Schnell. February 8, 2001.
Connecticut Department of Environmental Protection (CT DEP). 2001b. Draft "Permit for Fuel Burning Equipment" for Quinnipiac Energy, Air Bureau New Source Review section.
Connecticut Department of Transportation. 2001. Interstate 95 New Haven Harbor Crossing Corridor: Improvement Program. Online Posting. www.I95newhaven.com. April 10, 2001.
Connecticut Labor Department, Office of Research. 1999. Total Non-farm Employment by Town, New Haven Labor Market Area..
Cruz, Lee. 2001. Presentation to Industrial Ecology Class. February 2, 2001.
Damer, Dave. 2001. Wisvest Connecticut, formerly of United Illuminating. Telephone interviews. March and April 2001.
Doucette, Bill. 2001. Simkins Industries. Telephone interview and e-mail. April, 2001.
Douglas, Mark. 2001. Standard Tile. Telephone interview. April 2, 2001.
Dubno, Tom. 2001. Gateway Terminal Wholesale Yard. Telephone interview. March 23, 2001.
Empower New Haven. 2000. Empower New Haven, the first 21 months. September 2000.
Garvin, Alexander. 1996. *The American city: what works, what doesn't*. New York: McGraw-Hill.
Gillette, Jonathan H. 1982. Inside Contracting at the Sargent Hardware Company: A Case Study of a Factory in Transition at the Turn of the Century. unpublished seminar paper, Spring 1982. pp. 9-12
Gilvarg, Karen. 2001. Presentation to Yale F&ES Industrial Ecology Class. January 24, 2001.
Graedel, T. and B. Allenby. 1995. *Industrial Ecology*. Englewood Cliffs, NJ: Prentice Hall
Harrison, Henry S. 1995. *Harrison's illustrated guide to greater New Haven*. New Haven, CT: H2 Company. 184, 194-5.
Holzman, Michael. 2001. M.I. Holzman & Associates. Telephone interviews and e-mail. March and April 2001.
Johnston, Bruce. 2001. Sunshine Cleaners. Telephone interview. April 6, 2001.
Kleinbaum, Aaron. 2001. HB Ives. Telephone interview.
Mannis, Jeff. 2001. Quinnipiac Energy. Group tour of English Station in March 2001 and subsequent phone conversations in March and April 2001.
Mason, Simone. 2001. City of New Haven Department of Public Works. Telephone interview. April 6, 2001.
May, Cyril J. 2001. Yale University Recycling. Telephone interview. April 3, 2001.
McEneaney, Brenden. 2001. "RE: IE question for Long Wharf Group." Email to authors. April 8, 2001.
Montgomery County. 2001. Recycling Center. Online posting. http://www.mcrecycles.org/facilities/recyclingcenter.htm.
Mucci, Don. 2001. Recycled Concrete Products. Telephone interview. April 2, 2001.
Oszurak, Paul. 2001. St. Gobain Performance Plastics. Telephone interview. April 2001.
Raisch Products. 2001. Construction and Demolition Reuse/Recycling Ecological Park. online posting. http://www.raischproducts.com/NewsStand3.html.
State of Connecticut. 1999. Proposed Solid Waste Management Plan: Minimizing Disposal in the 21st Century. Arthur J. Rocque, Jr., Commissioner. December 1999.
Suzio, Leonardo H. 2001. Survey of processes and materials used by the L. Suzio Concrete Company, Inc. (faxed on April 4, 2001).
Suzio, Leonardo H. 2001. L. Suzio Concrete Company. Telephone interview. April 9, 2001.
Townsend, Doris B. 1976. *Fair Haven: A Journey Through Time*. New Haven: New Haven Colony Historical Society:17.

FURTHER INFORMATION

Anderson, Steve. 2001. Hershman Recycling. Telephone interview. 3 April.

Chertow, Marian. 2000. Industrial Symbiosis: Literature and Taxonomy. *Annual Review of Energy and Environment.* 25:313-37.

Cleanup City. 2001. On-line posting. http://www.1800cleanup.org/.

Cornell's Center for the Environment. Fairfield Ecological Industrial Park Baseline Study, 1995. Online posting.

Dunn, Stephen V. 1995. Eco-Industrial Parks: A Common Sense Approach to Environmental Protection. Yale University.

Ehrenfeld, John and Nicholas Gertler. 1996. Industrial Ecology in Practice: The Kalundborg Industrial Ecosystem. *Journal of Industrial Ecology.* 1:1.

Esty, Daniel, and Michael Porter. 1997. Industrial Ecology and Competitiveness. Online posting, http://elsinore.cis.yale.edu/envirocenter/bios/indecol.html.

Salvesen, David. 1996. Making industrial parks sustainable. *Urban Land.* February, 1996:32.

Part V: Exercises for Executive Education and Classroom Use

Eco-Industrial Development Primer

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ABSTRACT
What follows is a sample class exercise on Industrial Ecosystems created for the Yale School of Forestry & Environmental Studies *Corporate Environmental Leadership Seminar*. The Seminar is for senior environmental managers from the private and public sectors. This sample can be used as a template for teaching eco-industrial development concepts in industrial regions around the world (for example see *Hedges*, this volume).

INTRODUCTION

Industrial ecology, the marriage of ecology and technology, views industrial systems in concert with their surroundings, not in isolation from them. Industrial ecology studies the flow of energy and materials though various systems, thus bringing together environmental sciences, engineering, management and policy. The eco-industrial development concept – derived from the field of industrial ecology – is broadly based on the idea that one company's wastes can become another company's raw materials.

This primer serves as a background document to assist you in the Eco-Industrial Development Exercise.

BACKGROUND ON ECO-INDUSTRIAL DEVELOPMENT

A few key terms and principles should be defined at the outset to give a better understanding of eco-industrial development:

- **Industrial symbiosis** is one form of eco-industrial collaboration between traditionally separate industries in the industrial ecosystem. As in biological symbiotic relationships in nature, at least two willing participants exchange materials, energy, or information in a mutually beneficial manner. In industry these materials would most likely otherwise go to "waste."
- **Waste exchange** (**or "green twinning"**) is the least complex form of industrial symbiosis. Generally, this occurs when two companies exchange materials based on mutual economic benefit. Waste exchange may be a one-time, informal arrangement or a long-term, formal contractual agreement. Two companies need not be closely located, and in some cases a third party may act as a broker or facilitator of the exchange.
- **Eco-industrial parks** (**EIPs**) are more complex forms of industrial symbiosis. An EIP is best defined as a community of manufacturing and service businesses seeking enhanced environmental and economic performance through collaboration in managing environmental and resource issues. At the heart of the EIP concept is this exchange of

materials where one facility's waste (energy, water, materials, or "information") is another facility's input. By working together, the community of businesses seek a collective benefit that is greater than the sum of the individual benefits each company would realize if it optimized its individual performance only. Not to be overlooked are the social benefits that follow from EIP development, including fostering a sense of community among businesses and surrounding neighborhoods. Industries participating in an EIP can be located within the confines of a traditional industrial park, or can be connected "virtually" in a regional network. It is our belief that the benefits of an EIP can be expanded to encompass an entire regional economic community in which the potential for the identification of beneficial feedstock and waste trades is greatly increased.

- **Environmental benefits** are realized in eco-industrial development through:
  - reduced energy consumption and increased efficiency from energy cascading, co-generation, and utilization of waste heat from industrial processes
  - reduced water consumption and increased water use efficiency from closed-loop water use and gray water recycling
  - waste minimization from internal cycling of materials where residues from one process or industry are re-sold as feedstocks to other industries
  - reduced total environmental costs from virgin mineral extraction, including extraction, smelting, processing, forming, and transporting, when recycled materials from within the eco-industrial system are reused
  - brownfield redevelopment, whereby eco-industrial developments are located in existing industrial areas and help facilitate a co-location and linking of businesses instead of the current trend of greenfield expansion and dispersion of industrial sites
- **Economic benefits** flow from these environmental benefits, realized in costs avoided for waste disposal, reductions in raw material purchases, and from shared/centralized materials management services. As a brief hypothetical example of such accounting, imagine that an industrial firm produces 10 tons of organic waste per month that it pays $500 to dump. A nearby nursery spends $500 per month to purchase similar organic material. If these two firms were matched, they might agree to trade the waste, splitting the cost of transportation (perhaps $100 each). Each month then the industrial firm saves $400, the nursery saves $400, 10 tons of residues are recycled, and as much as 10 tons of virgin materials are saved. Eco-industrial development provides a fresh, new

approach to economic development by seeking business not on the basis of a promotional campaign, but by pointing out true economic opportunities where feedstocks may exist at reduced costs, and where materials formerly discarded as wastes have value.

INDUSTRIAL SYMBIOSIS AT KALUNDBORG, DENMARK

The archetype for eco-industrial development occurs in the small town of Kalundborg, Denmark. This well-documented example has developed over 30 years between large and small industrial firms in the social community of Kalundborg. Participants realized economic and environmental benefits through their agreements, without becoming cognizant of the fascinating network they had created until much later. Figure 1 below outlines the major flows of materials and energy that drive the industrial symbiosis at Kalundborg.

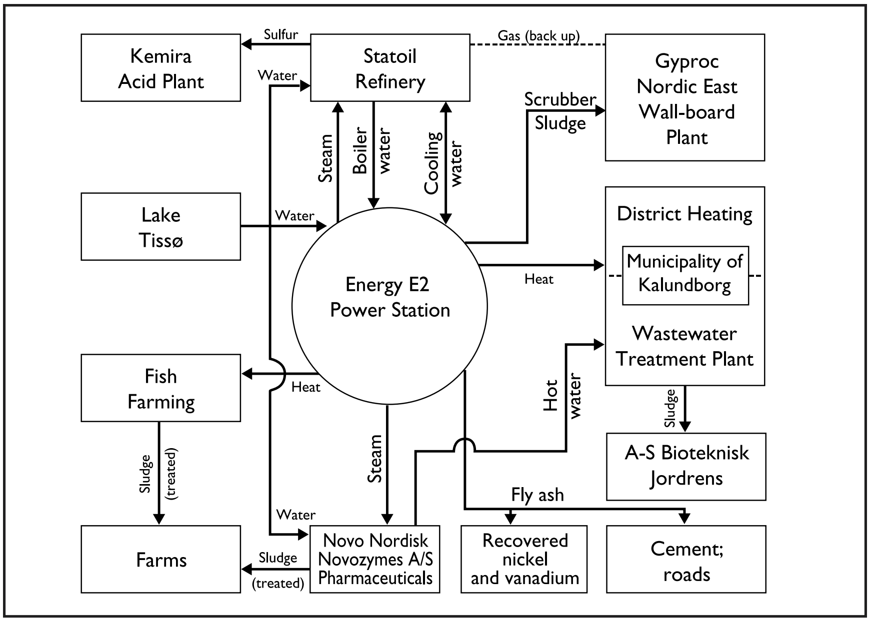


Figure 1 Industrial symbiosis at Kalundborg, Denmark

Kalundborg's industrial network behaves very much like an ecological food web, where industrial organisms consume each other's waste materials and energy, forming bonds of interdependence. The Kalundborg eco-industrial system includes six core partners: the 1,500 megawatt Energy E2 Power Station, the Statoil Refinery, the Gyproc plasterboard manufacturer, the Novo Nordisk/Novozymes pharmaceutical company, Bioteknisk Jordrens and the City of Kalundborg. The power station provides waste steam heat to the 20,000 residents of Kalundborg (for home heating) and to Novo and the Statoil oil refinery for their industrial processes. The major facilities use freshwater from Lake Tissø for cooling and have established wastewater networks, as well.

A small portion of the surplus-heated water was transferred to nearby aquaculture fishponds. A cement company utilizes the desulfurized fly ash from the power plant. The power plant reacts the SO_2 in the stack gas with calcium carbonate to produce calcium sulfate (gypsum) which is in turn sold to Gyproc. Historically, the refinery has provided excess gas (that otherwise would be flared off) to Gyproc as a low-cost alternative fuel source; however, this exchange has recently stopped. The refinery's desulfurization operation produces a product used in liquid fertilizer. Sludge from the fermenting and other biological processes at Novo and from the fish farms are used as soil enhancers in nearby farms. Local farmers use surplus yeast from the insulin production as pig food. The "community" nature of the eco-industrial park system is a key element in its growth and longevity.

ADDITIONAL READING AND USEFUL WEB SITES FOR FUTURE REFERENCE

Research Papers

Allen, D., and N. Behmanish.1994. Wastes as raw materials. *The Greening of Industrial Ecosystems.* Washington, D.C.: National Academy Press, pp. 69-89.

Chertow, M. Industrial symbiosis: Literature and Taxonomy. *Annual Review of Energy and Environment*, Vol. 25, 2000.

Ehrenfeld, J.R., and N. Gertler. 1997. Industrial ecology in practice: The evolution of interdependence at Kalundborg. *Journal of Industrial Ecology*, 1(1), 67-79.

Gertler, N., and J.R. Ehrenfeld. 1996. A down-to-earth approach to clean production. *Technology Review*, 99(2): 48-54.

Hawken, P. 1993. Creation of Waste. Chapter 3 in *The Ecology of Commerce*, New York: Harper Business, pp. 37-56.

Lowe, E.A., J. Warren, and S. Moran. 1997. Industrial ecosystems and eco-industrial parks. *Discovering Industrial Ecology: An Executive Briefing and Sourcebook*, Columbus: Battelle Press, pp. 129-158.

Porter, M.E., and C. van der Linde. 1995. Green and competitive: Ending the stalemate. *Harvard Business Review*, 73(5): 120-134.

Web Sites

Cornell Work and Environment Initiative Eco-Industrial Development Page
http://www.cfe.cornell.edu/wei/EIDP/eid.html

Indigo Development EcoPark Page
http://www.indigodev.com/Ecoparks.html

Research Triangle Institute - Eco-Industrial Park Page
http://www.rti.org/units/ssid/cer/parks.cfm

Corporate Environmental Leadership Seminar
Yale School of Forestry & Environmental Studies

June 4 -15, 2000

Robert J. Klee
M.E.S., Yale School of Forestry & Environmental Studies, 1999

ECO-INDUSTRIAL DEVELOPMENT EXERCISE: NEW HAVEN HARBOR

In this group exercise, you will be tasked with re-developing the New Haven, Connecticut Harbor region using the principles of industrial ecology and following the eco-industrial park model. We will take a field trip to the area, driving in vans through the neighborhoods surrounding New Haven Harbor, where you will view representative industrial sites in the community. You will be provided selected materials – flow information, which will allow you to begin to develop potential materials exchanges between a network of companies and municipal facilities, including the large power station, small auto shops, small metal fabrication facilities, the sewage treatment plant, local parks, and residential housing. You will also be able to suggest additional companies or facilities that would be well suited to locate in an eco-industrial development in the New Haven Harbor region.

NEW HAVEN HARBOR HISTORY

Around four hundred years ago, the area that is now New Haven was the home of a small tribe of Native Americans, the Quinnipiack, who built their villages around the harbor. On April 24, 1638, a company of five hundred English Puritans led by the Reverend John Davenport and Theophilus Eaton, a wealthy London merchant, sailed into the harbor. Pequot and Mohawk raiders from the surrounding areas were harassing the Quinnipiacks and other local tribes. The Quinnipiacks agreed to sell the tribe's land to the Puritans in return for protection and the use of the lands on the east shore of the harbor (where today's tour will end). New Haven's founders not only hoped to create a Christian utopia, they also saw New Haven's spacious harbor as an opportunity to establish a commercial empire that would control Long Island Sound and much of the New England coast. Over the next few years, however, the flow of newcomers to New Haven dwindled and trade with the outside world shifted more and more to Boston. In an attempt to establish direct trade with England, the settlers managed to assemble enough produce to fill a vessel that would become known as the "Great Shippe." However, after setting sail in January 1646, the ship and its crew were never heard from again. This disaster ended the dream of creating an economic empire, as New Haven was rapidly overshadowed by New Amsterdam (New York City) and Boston.

By the time the Revolutionary War began, New Haven had evolved from a colonial village into a growing town of about 3,500 that would contribute men, financial support and arms to the revolutionary cause. Industry grew around the harbor and along the rivers that flowed into the harbor. Eli Whitney (a Yale graduate and inventor of interchangeable parts and the cotton gin) established the Whitney Arms Company along the Hamden border, which was eventually bought by the Winchester Arms Company. Winchester Arms Company became one of New Haven's largest employers and helped establish New Haven as one of the major American arms manufacturing locations. Up until the 1950s, New Haven industries (many located in the harbor region) produced a wide range of products, including clocks, carriages, rubber goods, door locks, beer, pianos, plows, wagons, guns, and clothing. However, after the 1950s, new roads and the increasing availability of the automobile opened the floodgates on the middle class exodus to the suburbs. As suburban communities gave birth to industrial parks and shopping centers, New Haven's economic condition became progressively worse, and industrial activity in the Harbor area steadily declined. As you will see during the tour, many of New Haven's large industrial facilities have been replaced by a dispersed assortment of smaller manufacturing and service operations.

SCHEDULE OF EVENTS

12:15 - 12:45 PM:	Travel and van tour from Bowers Hall to Wisvest New Haven Harbor Power Station (**follow guide below for highlights of van tour).**
12:45 - 1:15 PM:	Lunch at Wisvest New Haven Harbor Power Station.
1:15 - 1:30 PM:	Welcome and briefing on group exercise.
1:30 - 2:30 PM:	Group meetings to devise an eco-industrial development plan for the New Haven Harbor industrial ecosystem. Roof access at Wisvest New Haven Harbor Power Station may be possible for a "bird's eye view" of the local area, weather dependent.
2:30 - 3:00 PM:	Report group findings and discuss answers to eco-industrial development questions.
3:00 - 3:15 PM:	Board vans and return to hotel.

SUMMARY OF ECO-INDUSTRIAL DEVELOPMENT EXERCISE

There are three main steps to this afternoon's eco-industrial development exercise. First, on the way to lunch from Yale, you will be given a driving tour of the New Haven Harbor region. Please try to go in the same van as the rest of your pre-assigned group. Second (after lunch), you will work with your group to devise an eco-industrial development plan for the New Haven Harbor region based on industrial ecology, industrial symbiosis, and eco-industrial park concepts. Third, your group will present and discuss your answers to the three central questions with the other groups.

STEP 1:
VAN AND AERIAL TOUR OF NEW HAVEN HARBOR AREA

All participants will take part in a field trip to the industrial, residential, and parkland portions of the New Haven Harbor region. Refer to the following "points of interest" description and the map as your guide to the van and aerial tour. Feel free to ask your van driver to point out interesting sites. The tour will end at the Wisvest New Haven Harbor Power Station, which will serve as a home base for the exercise.

Points of interest

- Tour begins on Chapel Street, heading towards the Harbor area. Use the map in Figure 2 as a reference.
- Just before the Mill River Bridge, look to the right-hand side to see the Suzio Cement Mixing Company, easily recognized by the tall green and white cement tower.
- While going over the Mill River Bridge, look up river to the left to see the Quinnipiac Oyster Company and their heaps of oyster shells along the shore. Look down river to the right to see one of the many metal scrap yards that are located on this section of the Harbor.
- Traveling along Chapel Street, be sure to notice the pipe, plumbing, and metal working shops along the way. Pay particular attention to the large ladder and scaffolding factory on the right.
- The tour takes a right onto Ferry Street to go over the Ferry Street Bridge and the Quinnipiac River. Observe the large boat and barge repair docks on the left at the end of the Ferry Street Bridge.
- The tour will wind its way down through a mixed industrial and residential zone of auto repair shops, plumbing shops, small metal fabricators, and some now-abandoned buildings of the New Haven Terminal. To follow on the map, the vans will loop through Fairmont Avenue, Fulton Street, Forbes Avenue, Wheeler Street, Goodwin Street, and back to Forbes Avenue. Try to find the plumbing supply shop on Forbes Avenue that is located in what appears to have been a church.
- The tour will turn onto Waterfront Street, traveling past the petroleum tank farms of Gulf, Sunoco, and Global Petroleum. The tour then winds along Alabama Street, back to Fulton Street down towards the New Haven municipal wastewater treatment plant. At the end of the road (the circular turn-around) you can see the parking lots and basketball courts of East Shore Park.
- The driving tour ends at the Wisvest New Haven Harbor Power Station. Upon entering the power station, observe the high voltage transformers, the supplemental natural gas pipeline, the fuel oil unloading dock, fuel storage tanks, and the large smokestack.

- Weather permitting, the view from the roof of the Power Station shows the petroleum tank farms, cement plants, highways, and miscellaneous industrial facilities to the North; the municipal sewage treatment plant and East Shore Park to the South; the residential housing districts to the East; and New Haven Harbor to the West.

STEP 2: DEVISE AN ECO-INDUSTRIAL DEVELOPMENT PLAN FOR THE NEW HAVEN HARBOR REGION

Each group will create an eco-industrial development plan for the Harbor area of New Haven by incorporating the basic ideas of industrial ecology, industrial symbiosis, and eco-industrial parks. Each group can use the following information describing the material flows of potential participants in the New Haven Harbor eco-industrial development plan. In addition, be sure to draw upon the personal knowledge and experience of your group in devising additional industrial symbiosis linkages. Each group should try to quantify linkages of industrial systems whenever possible. Each group should develop a network flow diagram and should explore the economic and social aspects of the symbiotic relationships.

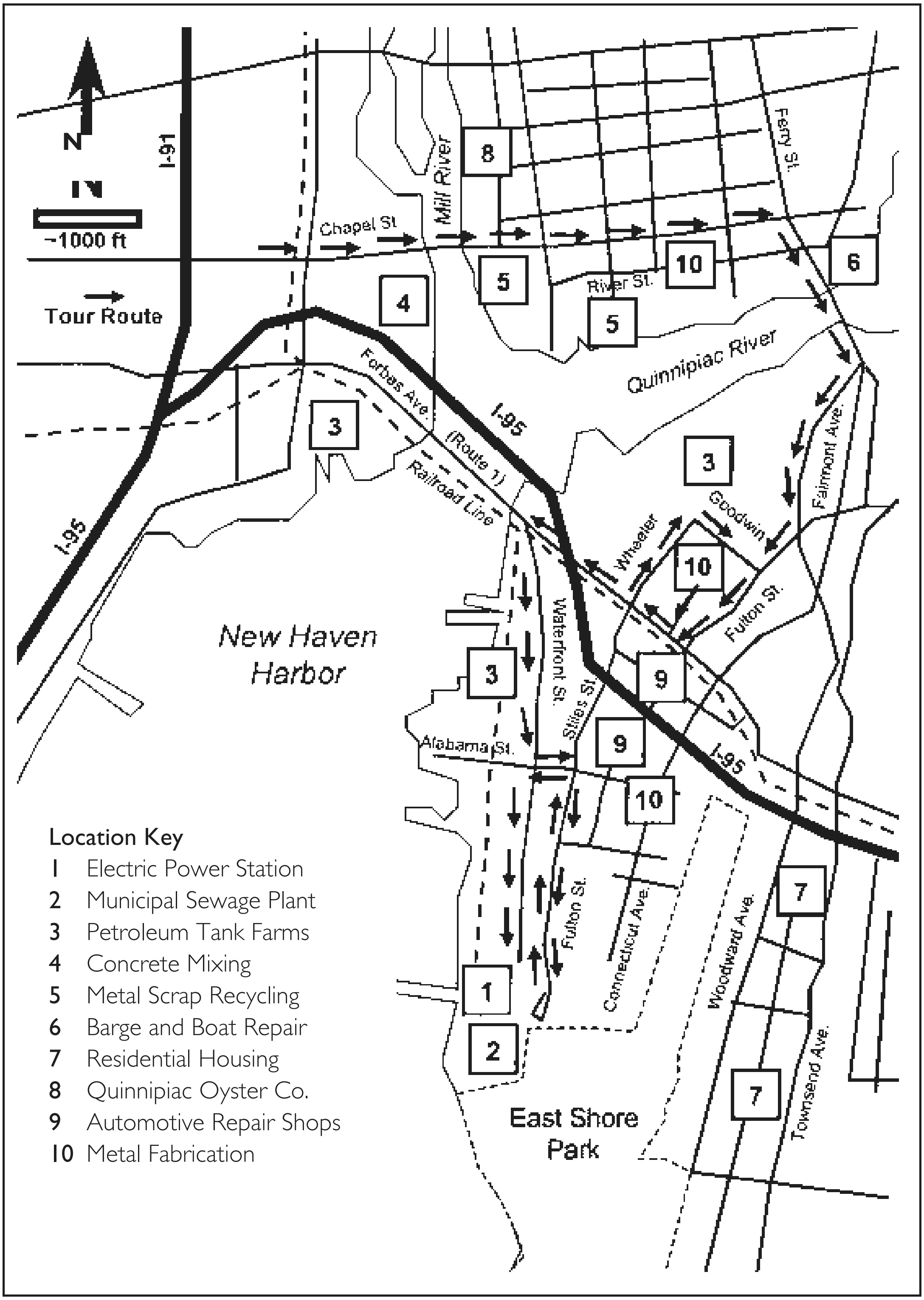
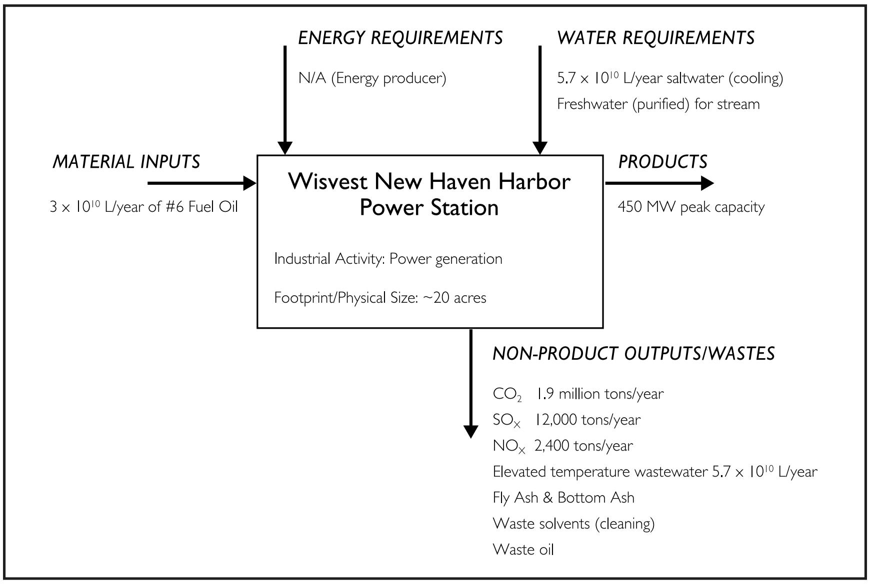


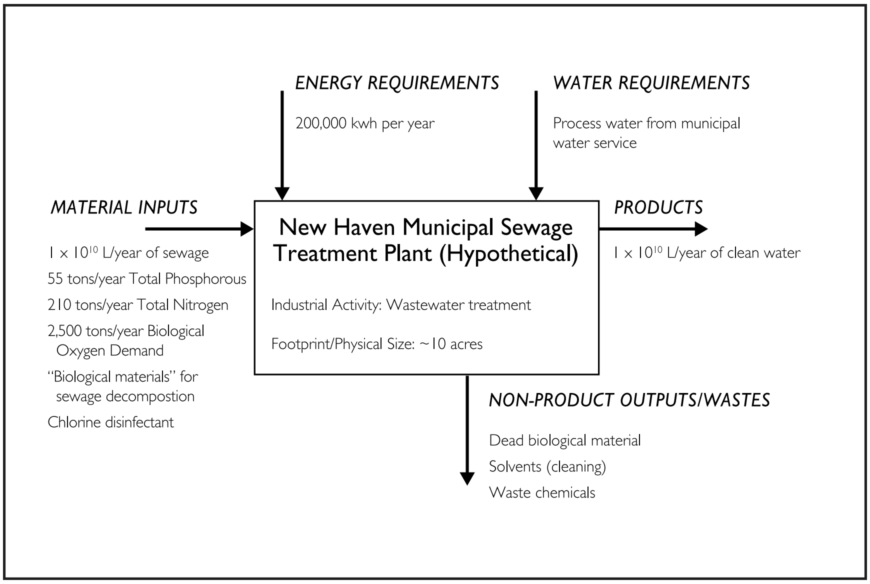
Figure 2 New Haven Harbor Industrial Zone Map

INDUSTRIAL FACILITY MATERIAL FLOW PROFILES

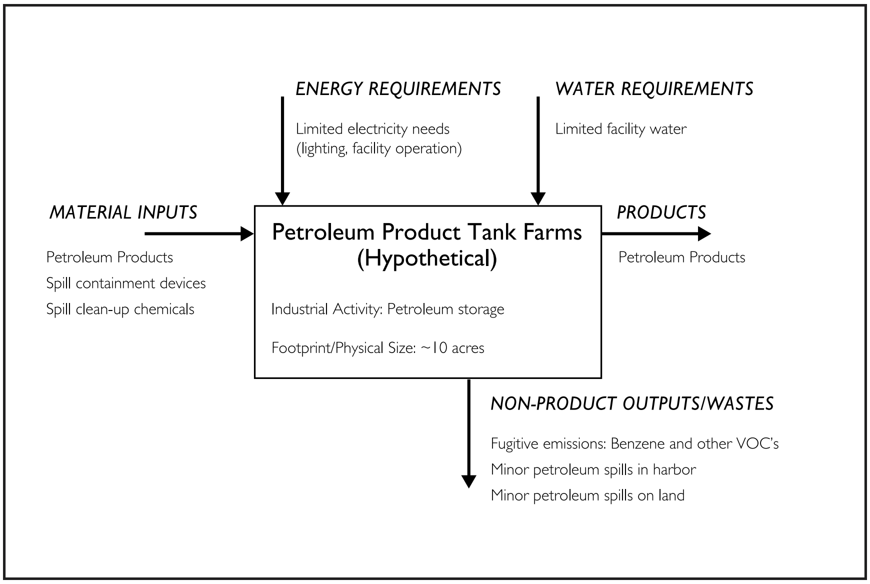
1. Electric Power Station



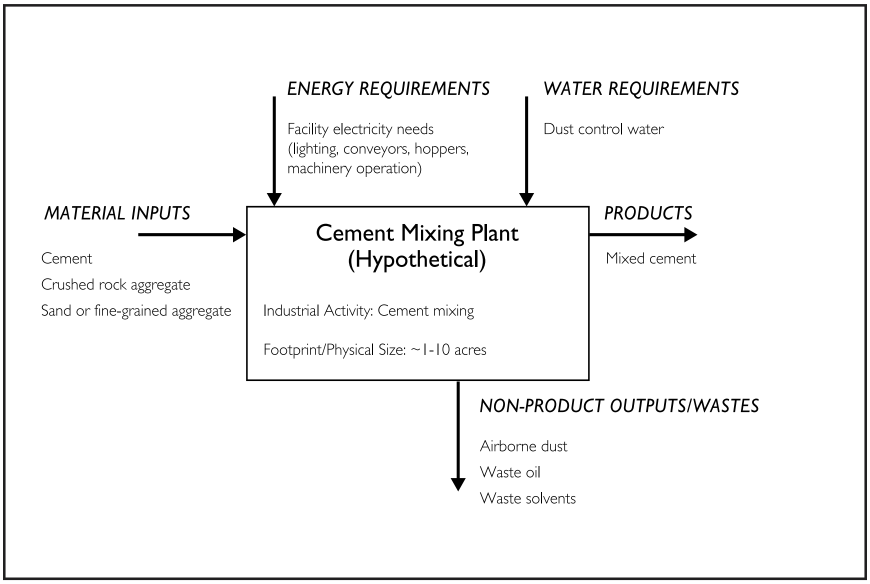
2. Municipal Sewage Plant



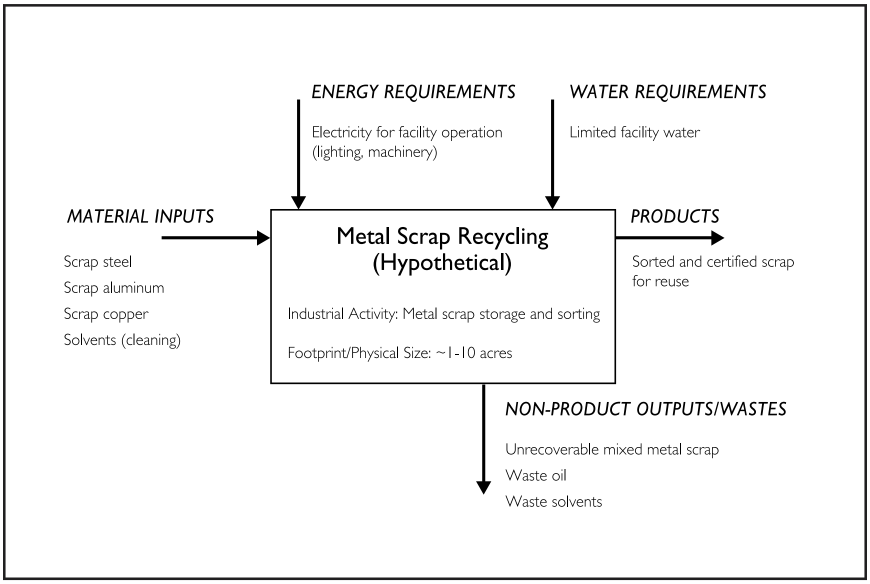
3. Petroleum Tank Farms



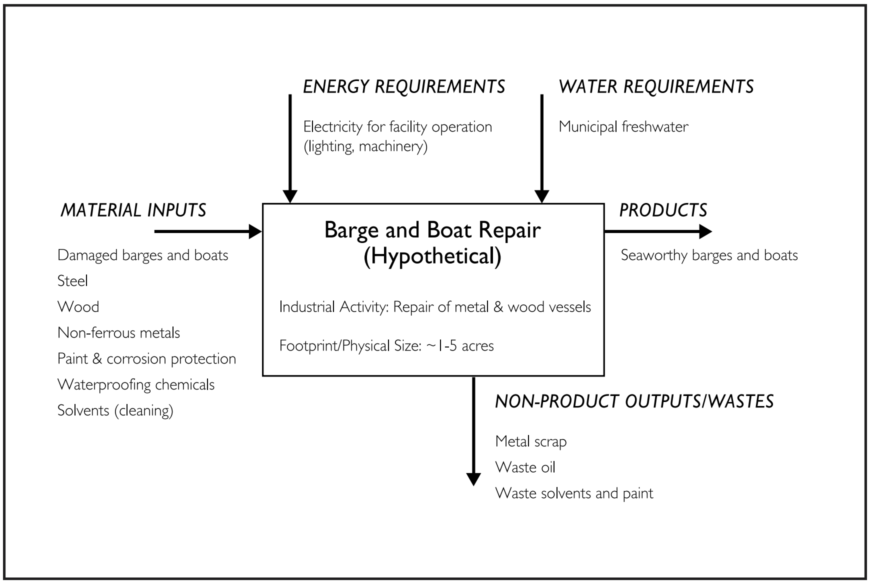
4. Concrete Mixing



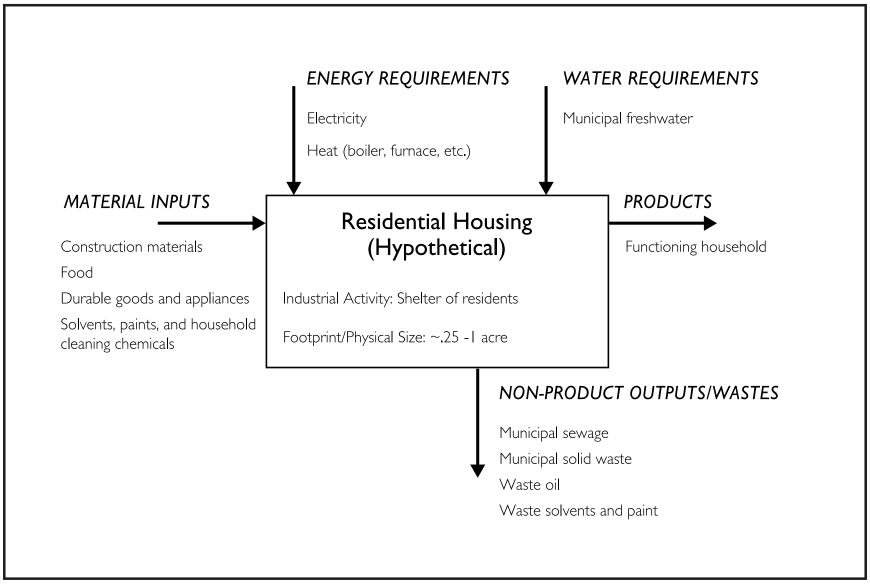
5. Metal Scrap Recycling



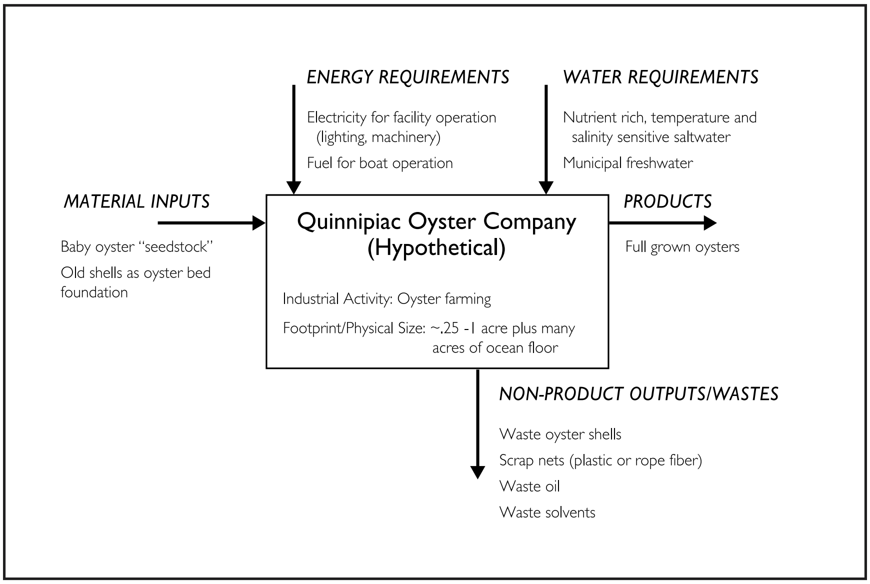
6. Barge and Boat Repair



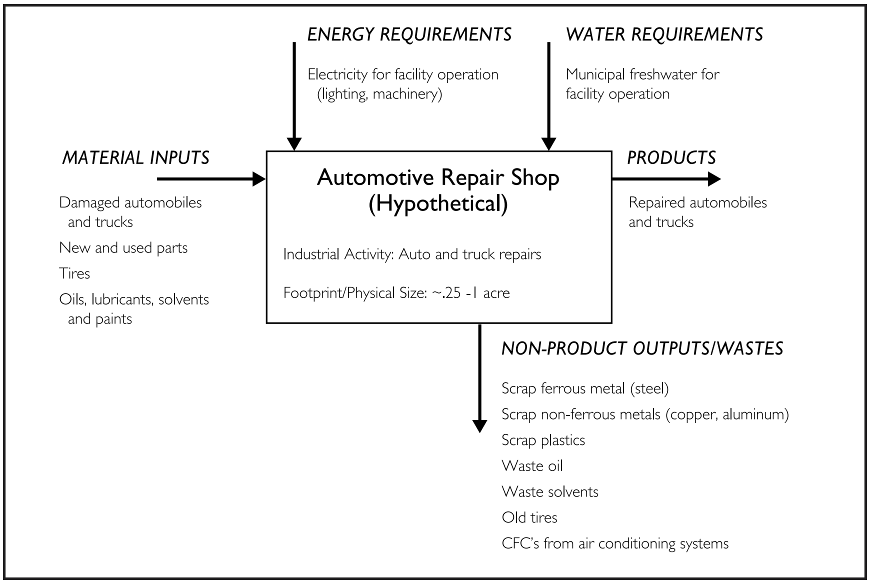
7. Residential Housing



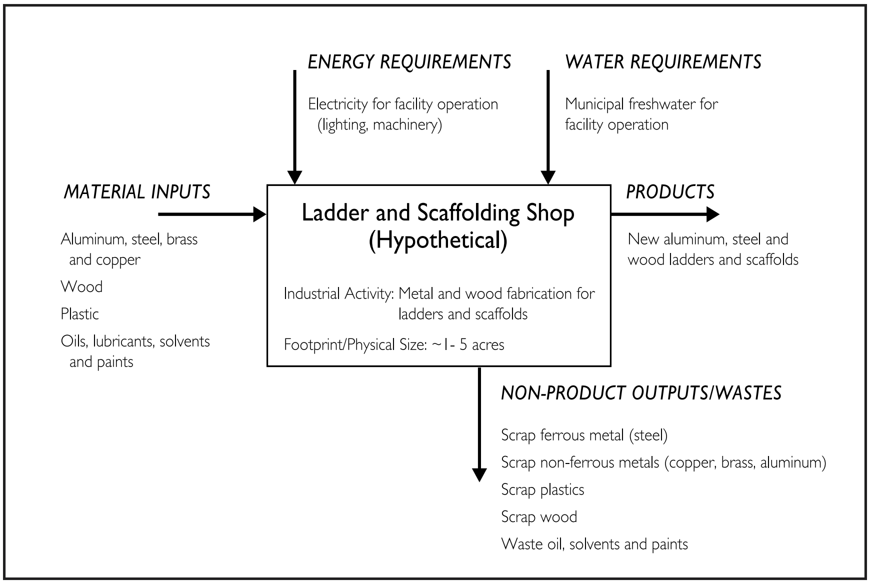
8. Quinnipiac Oyster Company



9. Automotive Repair Shops



10. Metal Fabrication - Ladder and Scaffold Example



STEP 3:
EXPLORE, DISCUSS, AND PRESENT GROUP FINDINGS ON THE CENTRAL QUESTIONS

Each team will explore the central questions below and will compare their findings with the other groups. Choose a group spokesperson to present your ideas to the other groups.

Central Questions for Eco-industrial Development Groups

1. What is your group's proposed near-term (5-10 year) eco-industrial development plan for the area? Specifically, what industrial symbiosis linkages are possible for the New Haven Harbor Industrial Zone? (A network flow diagram may be useful to clarify potential linkages).
2. What might you do differently in a long-term (20+ years) eco-industrial development plan for the area? (Feel free to think about extreme changes to the urban-industrial landscape).
3. What are potential companies that you would target to invite to the area to participate in the New Haven Harbor eco-industrial development in the near-term? In the long-term?

Sustainable Development Leadership Program
Yale School of Forestry & Environmental Studies and
Nanjing Forestry University, Nanjing, China

October 15-23, 2000

Scott Hedges
M.E.M., Yale School of Forestry & Environmental Studies, 2001

ECO-INDUSTRIAL DEVELOPMENT EXERCISE: NANJING, CHINA

This exercise is designed to encourage thought and discussion about the ways in which the principles of industrial ecology could be applied following the eco-industrial park model. It is based on a hypothetical set of industrial sites. For each of the sites basic materials flow information is given, which will allow you to develop potential materials exchanges between a network of companies and municipal facilities, including the large power station, a steel mill, an electronics factory, a sewage treatment plant, a cement factory, a scrap recycler, and residential housing. You are encouraged to suggest additional companies or facilities that would be well suited to locate in this eco-industrial project area.

DEVISE AN ECO-INDUSTRIAL DEVELOPMENT PLAN FOR NANJING

Each group will create an eco-industrial development plan for Nanjing by incorporating the basic ideas of industrial ecology, industrial symbiosis, and eco-industrial parks. Each group can use the following information describing the material flows of potential participants in the Nanjing eco-industrial development plan. In addition, be sure to draw upon the personal knowledge and experience of your group in devising additional industrial symbiosis linkages. Each group should try to quantify linkages of industrial systems whenever possible. Each group should develop a network flow diagram and should explore the economic and social aspects of the symbiotic relationships.

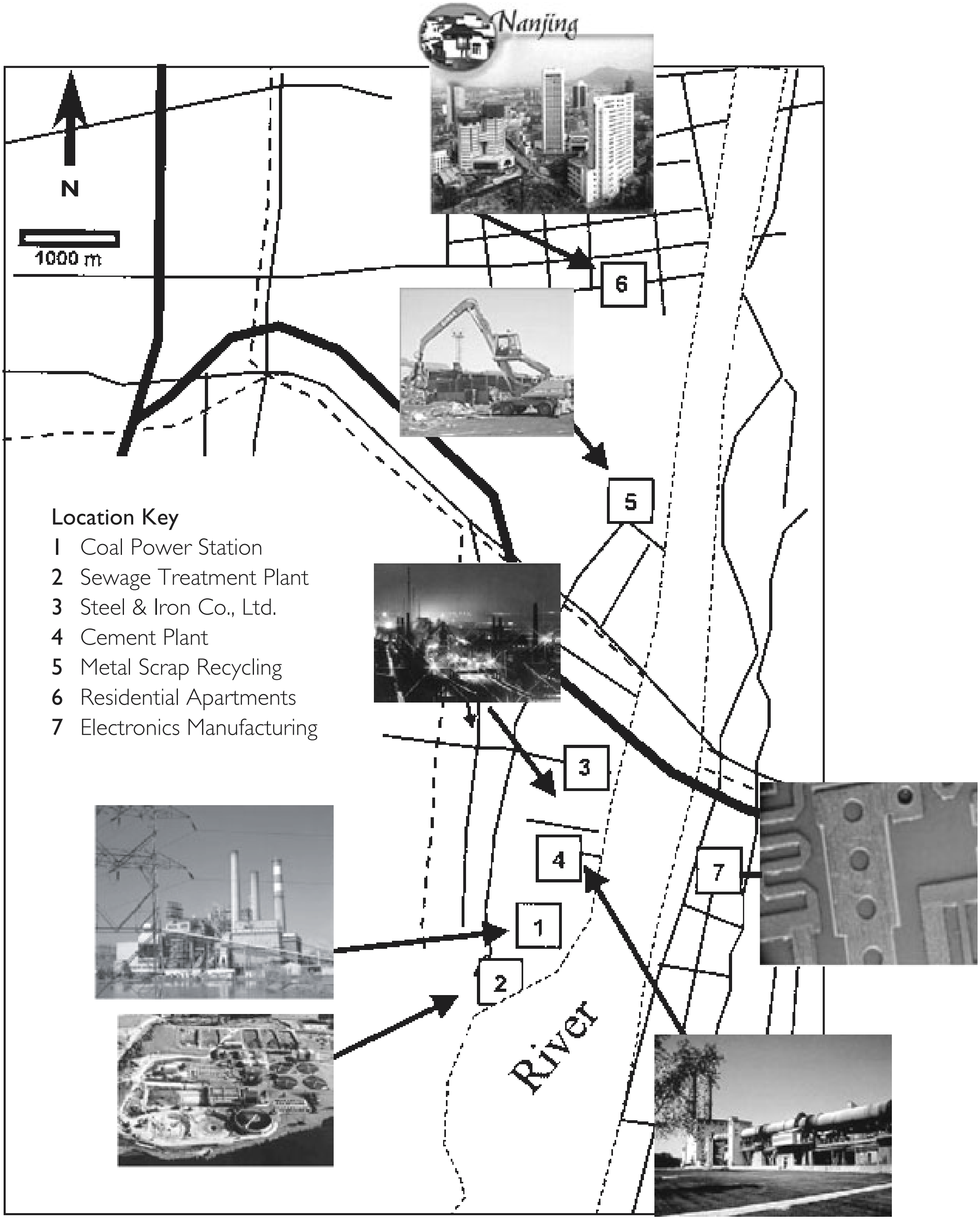
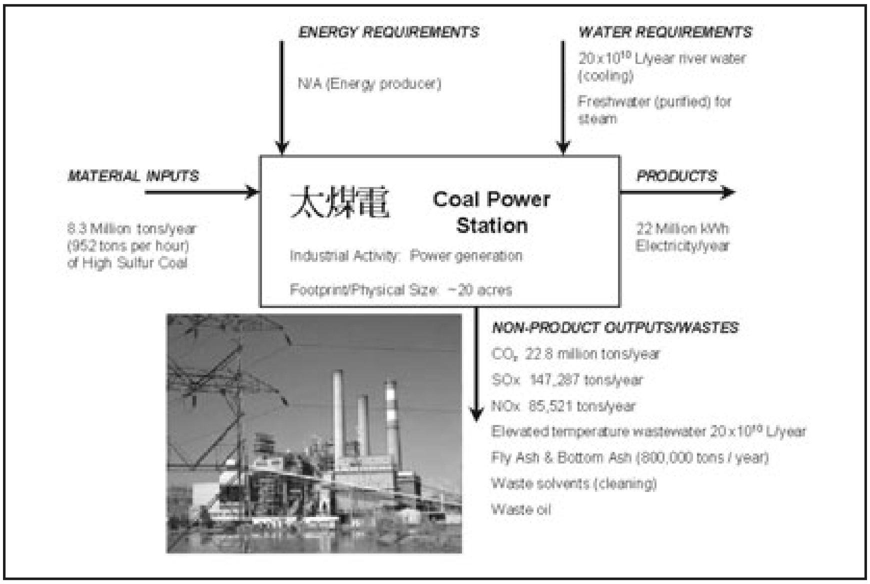


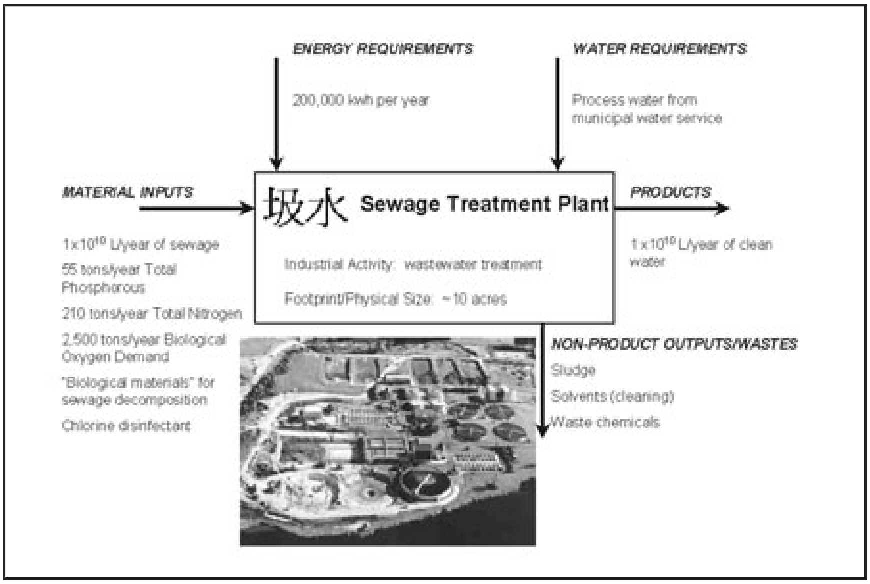
Figure 1 Nanjing, China Industrial Area Map

INDUSTRIAL FACILITY MATERIAL FLOW PROFILES

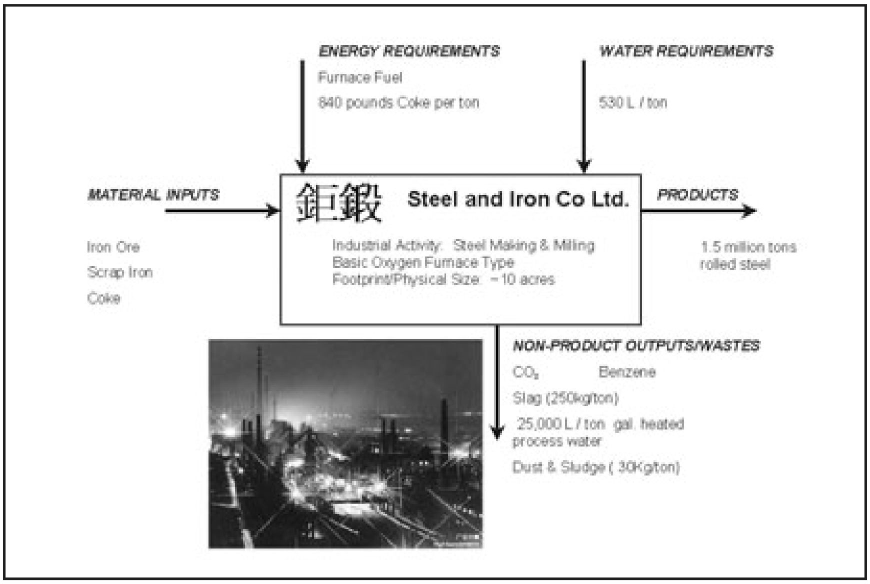
1. Coal Power Station



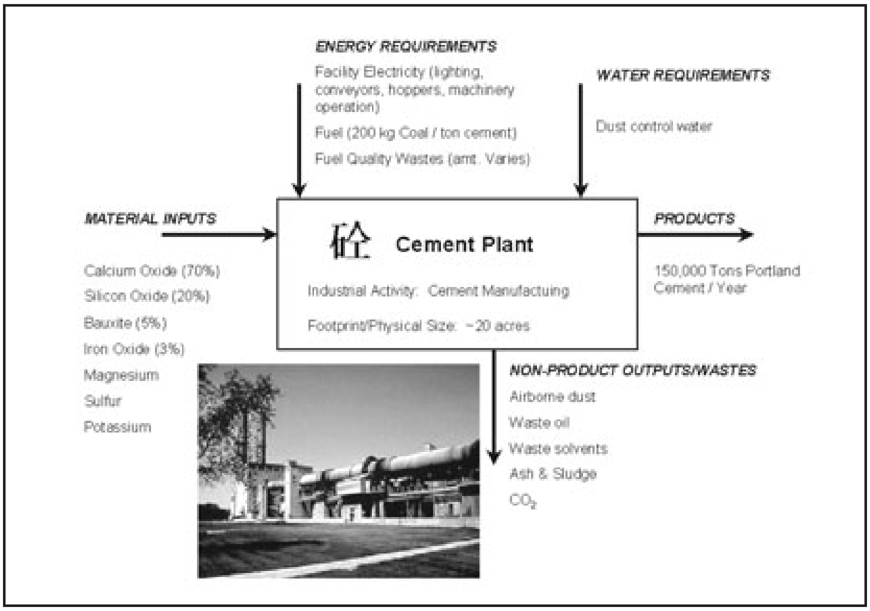
2. Sewage Treatment Plant



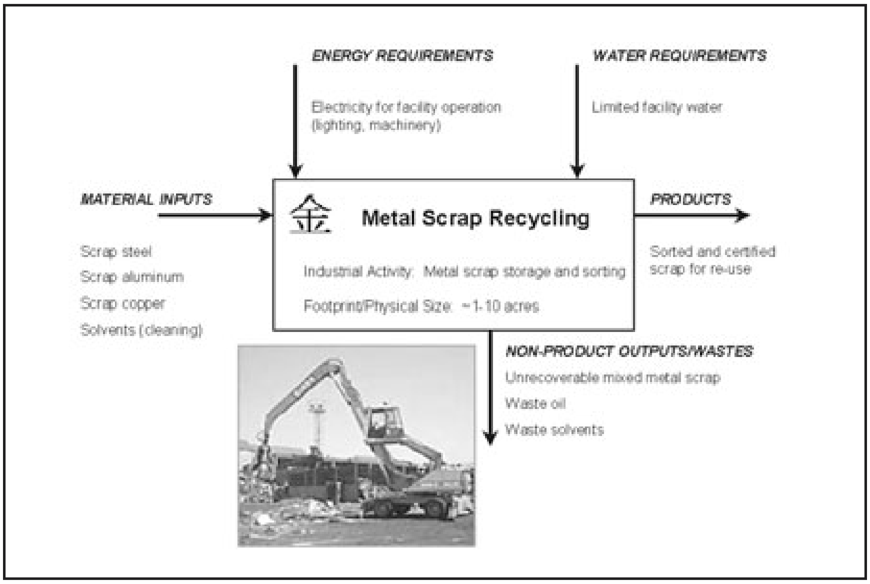
3. Steel and Iron Co., Ltd.



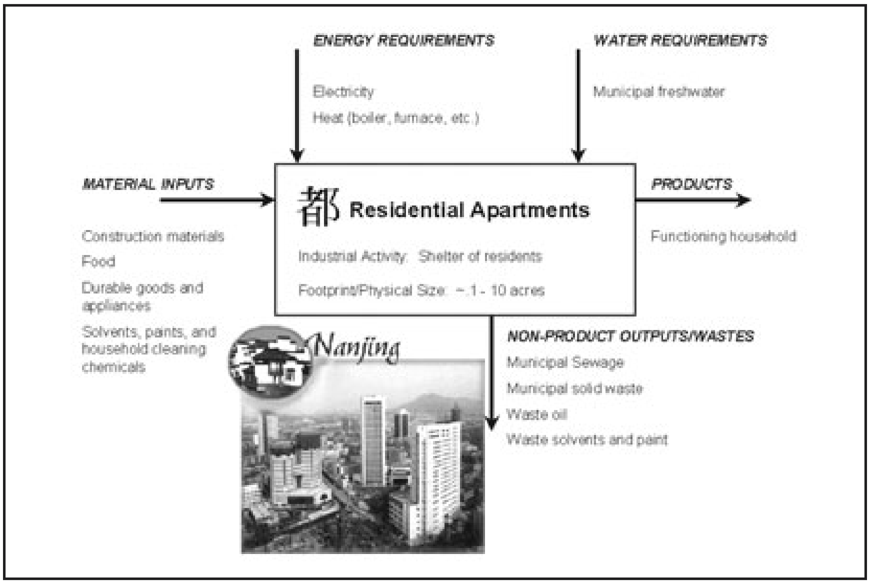
4. Cement Plant



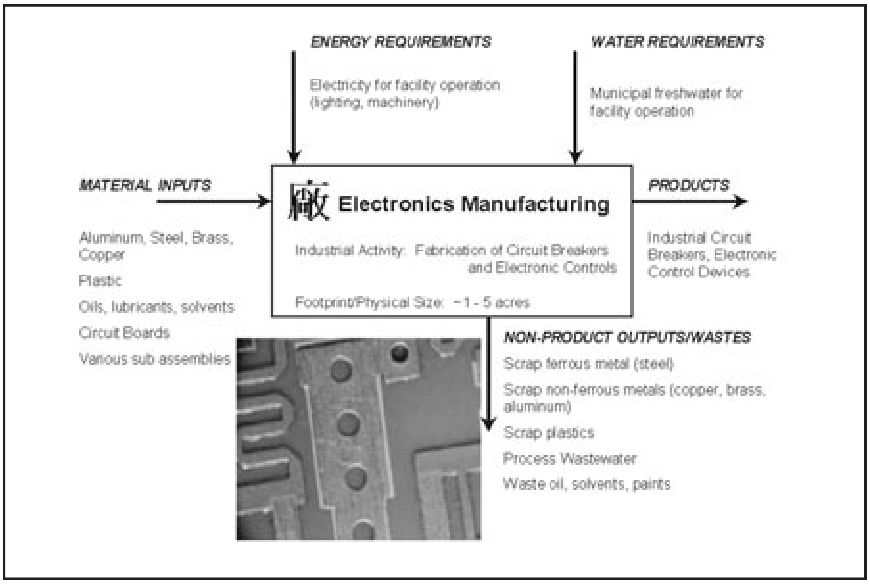
5. Metal Scrap Recycling



6. Residential Apartments



7. Electronics Manufacturing



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