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.

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).

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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).

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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.

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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.

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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).

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).

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).

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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.

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.

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).

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.

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.

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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).

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.

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.

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.

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.

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.

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.

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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.

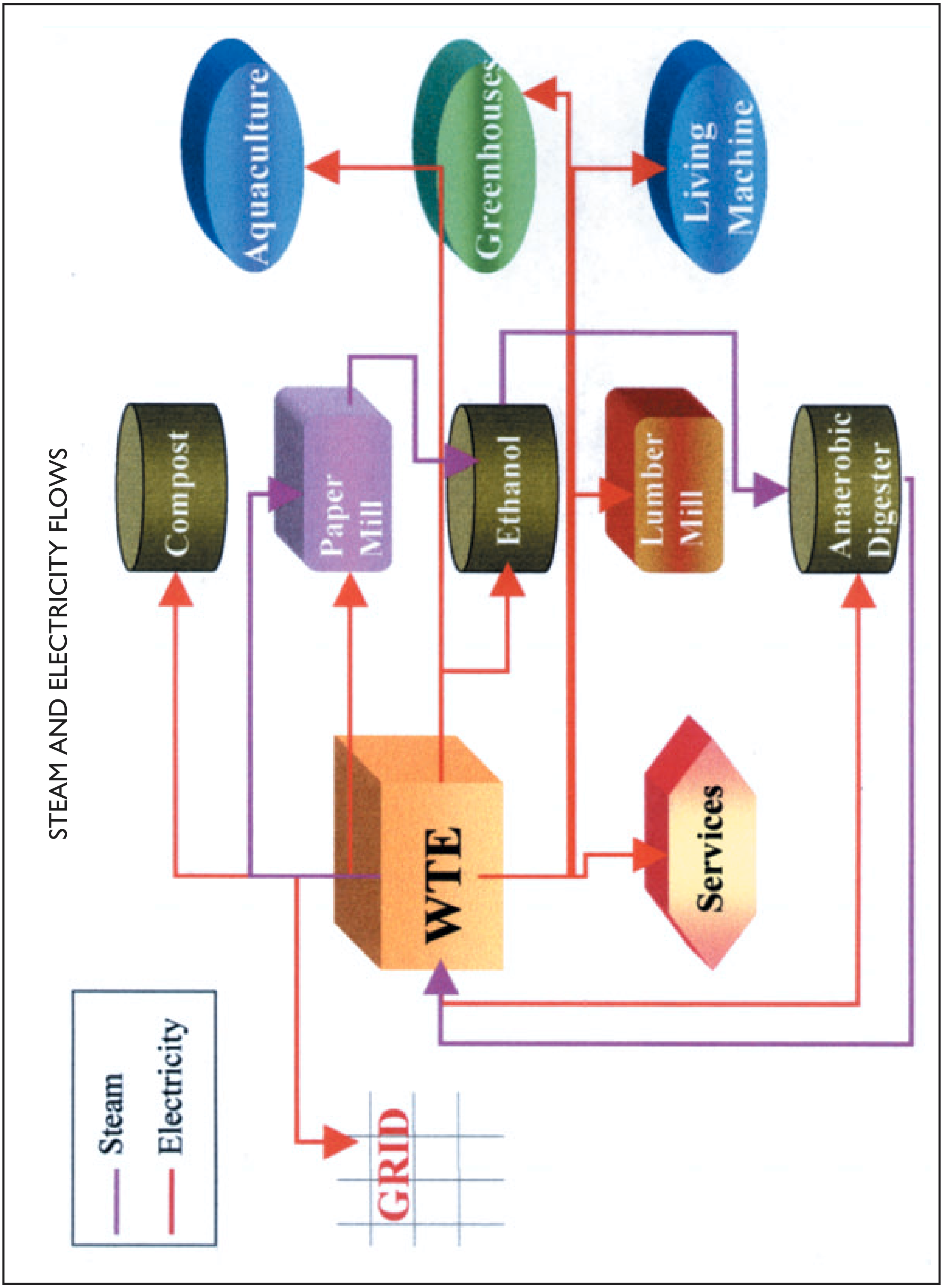

Figure 1 Steam and Electricity Flows

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

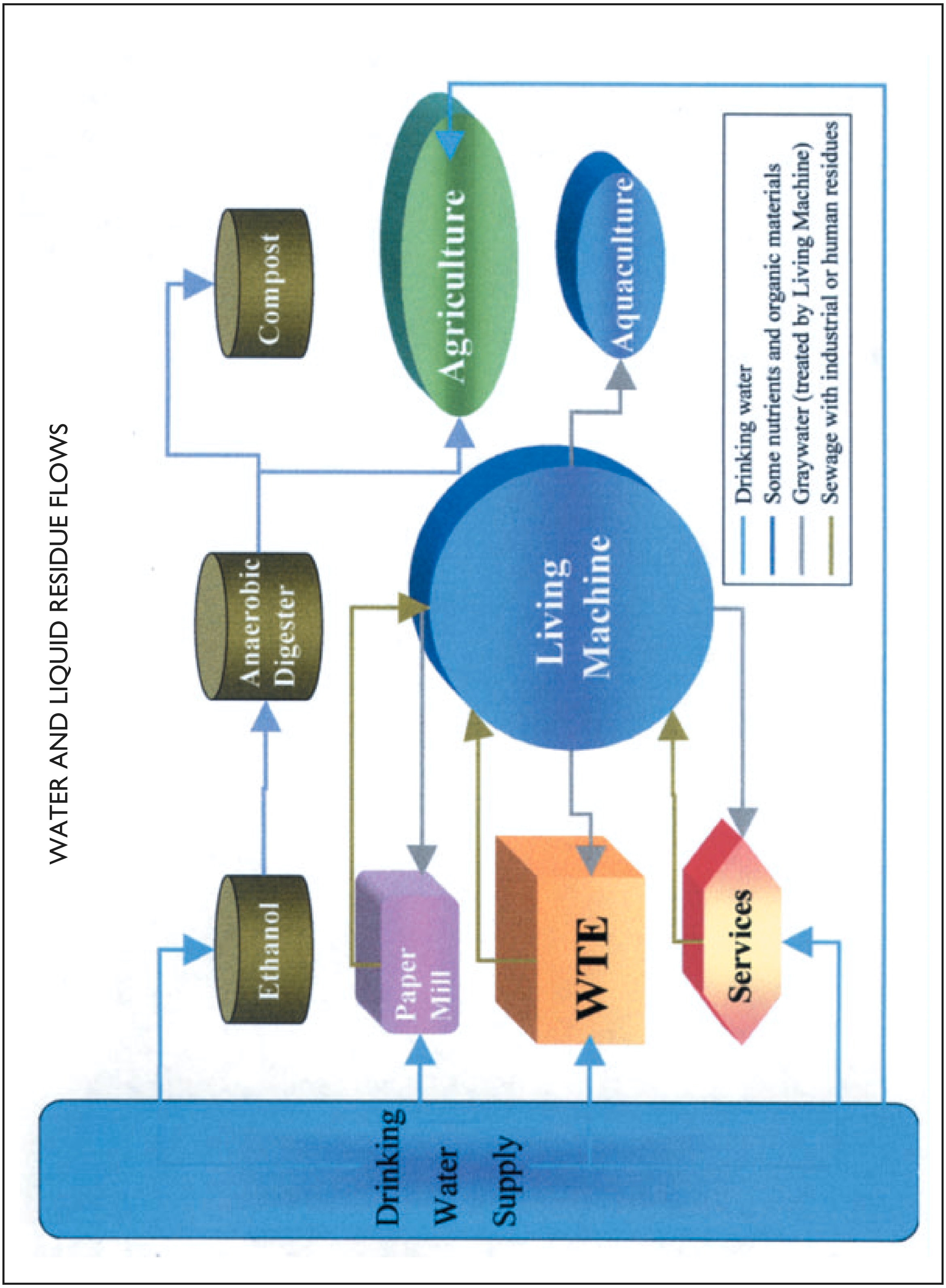

Figure 2 Water and Liquid Residue Flows

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.

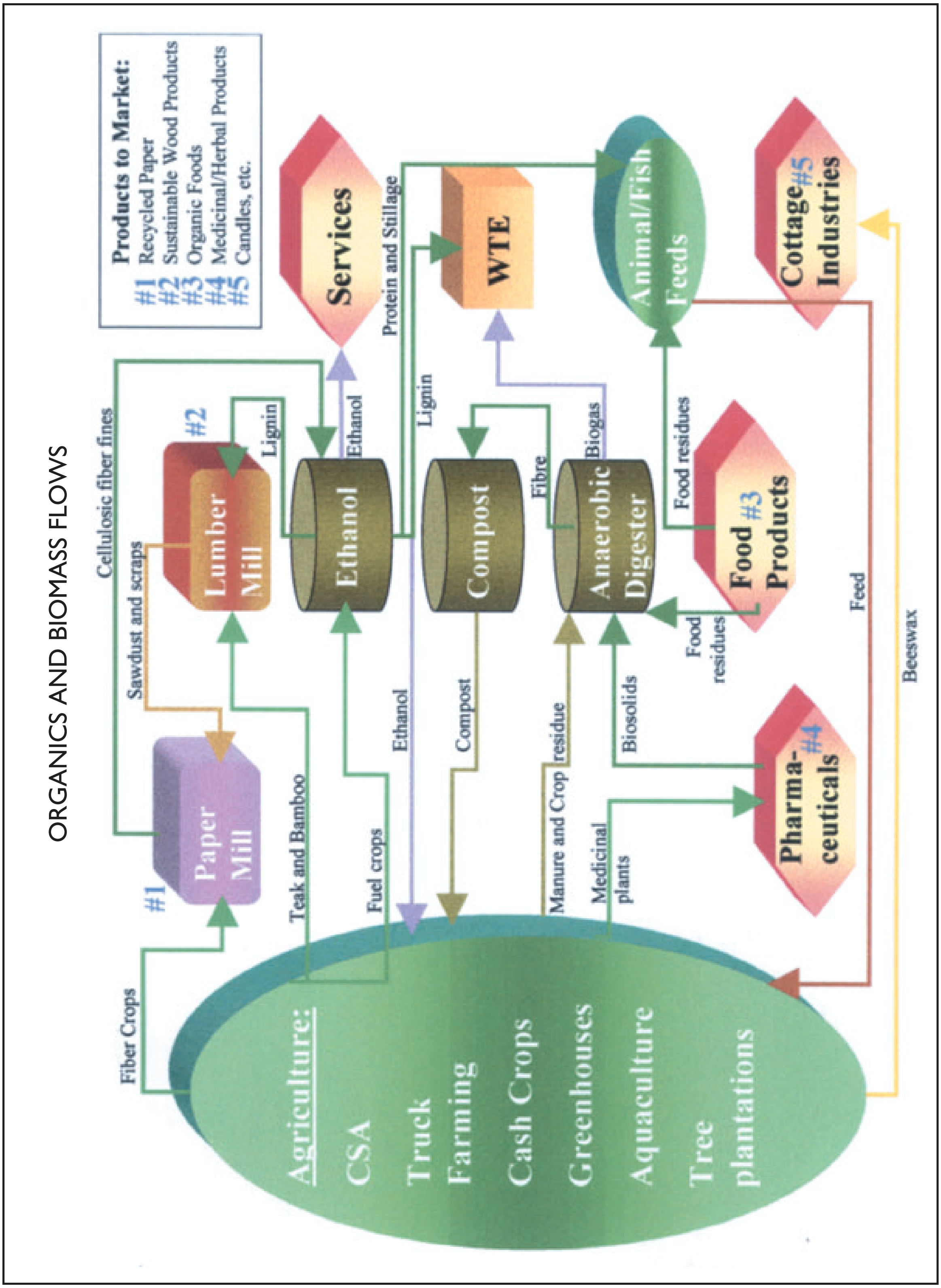

Figure 3 Organics and Biomass Flows

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 take back programs and improvements in recycling in Puerto Rico (helped by outreach program from Renova), fuel cell technology, light rail system	3	3	4	4	18
						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	2	1	**9**
	no change from Stage 2, no significant improvements to system					
						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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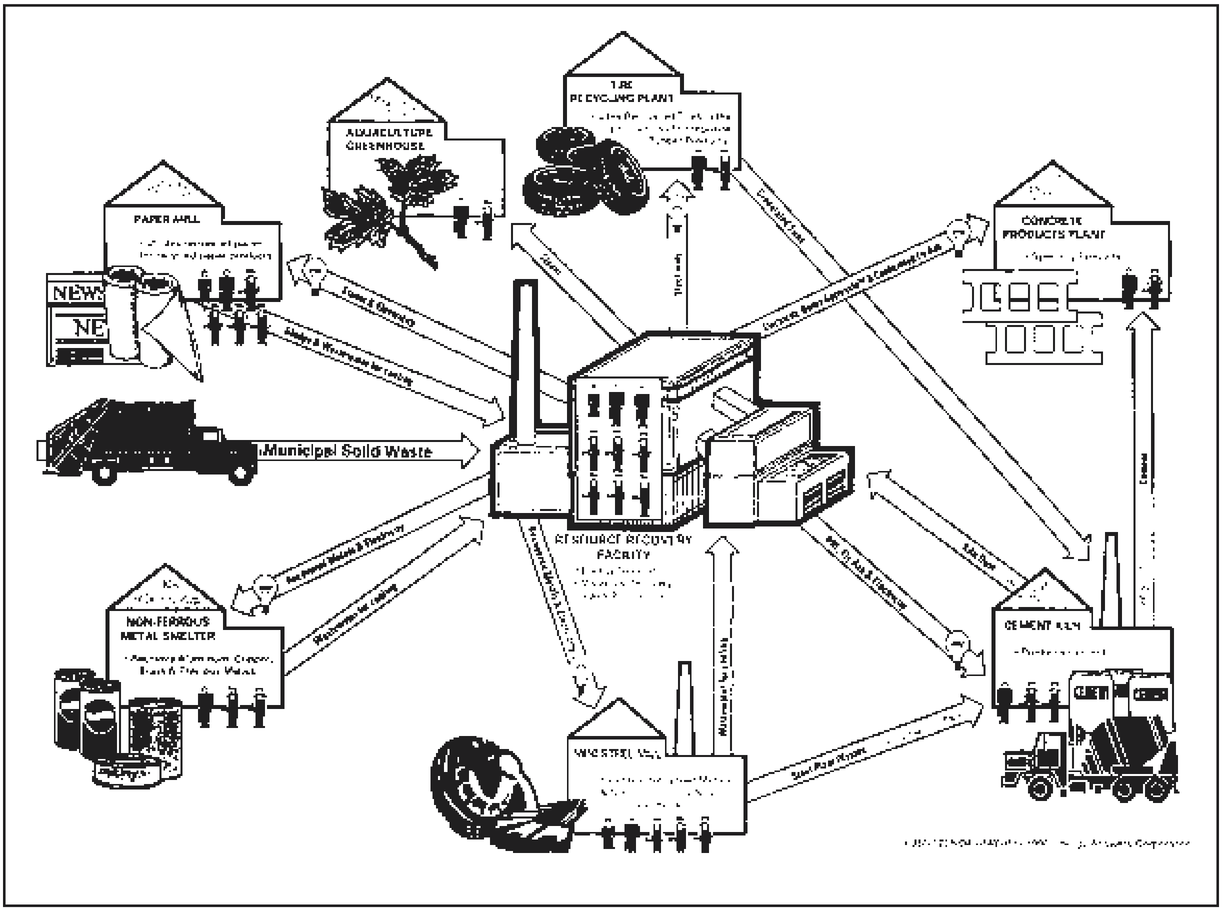
APPENDIX A Integrated Industrial Resource Recovery Complex



APPENDIX B Resource Recovery Process