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

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

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

MAKING THE CONNECTIONS
At present, the CSEZ is home to a number of industries that operate essentially independently from one another. In this exercise, we weave an intricate web of interdependent relationships among these various actors. This paper outlines recommendations for heat and energy flows, addresses water conservation and cycling, discusses oil and solvent recovery and reuse programs, and looks at material flows of compost and scrap tires.
HEAT AND ENERGY FLOWS
Using industrial symbiosis at Kalundborg as a model, we have placed the planned 250 MW oil-fired power plant at the heart of the CSEZ. In designing an eco-industrial park, a 50% reduction in energy consumption is feasible with utilization of waste steam heat from the power plant (Lowe et al. 1995). However, due to the tropical climate of the Philippines, use of the waste steam energy for home, office, and factory heating is not necessary. Therefore, waste steam energy utilization must be limited to industrial processes that require a heating or drying step. Before detailing the flows of waste steam heat at the CSEZ, we will evaluate the benefits of co-generation and estimate the possible steam quantities and temperatures.

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

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

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

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

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

Materials Flows of Steamheat Energy

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

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

The Clark Development Corporation plans to build greenhouses to grow landscaping plants for the eco-industrial park community and the golf courses (Magat 1998). Although in a tropical climate, the greenhouses would benefit...
from supplemental heat energy to ensure constant temperatures in the 25-100°C (80-212°F) range and could easily be implemented, considering the small quantities of steam required.

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

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

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**Figure 2 Heat/Energy Cascading**
peratures required for vulcanization are near the maximum estimated temperature ranges of the waste steam generated by the power plant. The overall feasibility of this proposed link will require further investigation.

**Short-Term Power Plant Options**

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

In addition to the 250 MW power plant, there is an outdated 50 MW power plant at the CSEZ, which is a relic of the Clark Air Force Base. This environmental liability was partially damaged by the eruption of Mt. Pinatubo in 1992 and has fallen into disrepair. Instead of demolition and costly clean-up, it may be possible to retro-fit this “brownfield” site to once again be a power generator, potentially fueled by tire and municipal waste. There are significant quantities of scrap tires and general household waste available to fuel a waste-to-energy power plant. Admittedly, this is a transfer of a solid waste emission to gaseous ($\text{CO}_2$) and solid waste emissions (scrubber sludge and furnace ash). However, the reduced impact on the island nation’s limited land area and the savings from disposal costs could be a net environmental benefit.

**Longer Term Conservation and Renewable Energy**

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

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

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

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

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

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

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

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

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

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

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

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

Recommendations for the Golf Courses

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

Long-Term Goals

In the longer term, industries throughout the CSEZ will be encouraged to cycle their water much more tightly. While the management can provide incentives for CSEZ tenants to conserve water resources, the biggest impetus for change would come from an increase in water prices to reflect its scarcity in the region. Current water prices for industrial customers are $0.9/m³ and $0.50/m³ for commercial customers (Businessworld 1997). Increases in these prices may provide some incentive for tighter water cycling. From the outset, the CSEZ...
should be actively promoting the long-term goal of water resource conservation. The CSEZ undoubtedly will benefit from increased self-sufficiency brought about by efficient water use through internal water cycling (Chin 1996).

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

**Electronics**

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

**Services/Housing**

For all uses both the services industry and residential housing are served primarily by water that is of drinking water quality. This is unnecessary because water that has been used for washing does not need to be considered sewage. In an attempt to maximize water use efficiency, buildings are increasingly being designed to incorporate dual pipe systems to separate waste water from gray water (Cote et al. 1995). One example of this is the Killington Ski Resort in Vermont. In the mountain lodges, water that has been used in basins provides the water for flushing toilets. This in turn becomes brown water or sewage and is treated as such. The cost of refitting existing plants at the CSEZ may be prohibitive, but as with the golf course, if it can be incorporated at a design stage of new facilities it could provide a huge benefit (Chin 1996).

**OIL RECYCLING**

One of the fundamental principles of an effective eco-industrial park is the pooling of ubiquitous, low-level waste streams for large-scale recovery and reuse. Used oil waste streams present such an opportunity at the CSEZ. There are two main uses for recycled oil: 1) it can be re-refined at large petroleum refineries and then used in combustion engines and as a lubricant, or 2) it can be burned as fuel, if the proper procedures and equipment are used. Most used oil is used as an industrial fuel source. Given the numerous industrial operations at the CSEZ and the lack of an on-site petroleum refinery, we suggest that used oil become an industrial fuel source at the CSEZ.

The recovery of waste oil makes sense not only from a resource conservation perspective (oil is a non-renewable resource), but also to prevent further contamination of the industrial park. When used oil is dumped onto the ground, down storm sewers, or sent to improperly contained landfills, it...
migrates into ground and surface waters and has an adverse impact on ecosystems and human health. Films of oil on the surface of water prevent the replenishment of dissolved oxygen, block sunlight, and impair photosynthetic processes. Aquatic species can be adversely affected by oil concentrations as low as one part per million (U.S. EPA 1989). As oil circulates through combustion engines and industrial machines it picks up dirt, rust, and metal particles. In addition, exhaust gases and fluids like antifreeze from engines, and solvents from machinery, can leak into oil. All of these substances increase the used oil’s toxicity to humans and to ecosystems. According to the U.S. EPA, one gallon of used oil from a single oil change can ruin one million gallons of fresh water—a year’s supply for 50 people (U.S. EPA 1989).

Sources of Used Oil
CSEZ has numerous sources of used oil that make it an ideal candidate for a used oil recovery program. Facilities from which used oil will be generated include:

- Seventy-eight industrial facilities, most of which use oils to lubricate their machines;
- Five utility service facilities;
- CSEZ’s Airport, which currently handles 1.5 million passengers per year and is anticipated to have to handle 15 million passengers per year;
- Gas stations;
- Vehicle fleets and individual cars associated with CSEZ’s 78 commercial businesses, 28 service industries, 11 tourism businesses, 4 housing ventures (300 housing units currently available, 550 under development), and 2 schools.

Short-Term Options for Spent Oil Recovery
Studies show that the primary barrier to a successful used oil recovery program is providing an easy way for people and facilities to get rid of used oil they have collected (U.S. EPA 1989). We propose that the Clark Development Corporation contract with a third party or investigate alternative means of establishing an oil collection service. The oil collection service would come to CSEZ industrial facilities, gas stations, and the airport on a bi-weekly basis and to residential housing unit collection areas and other service industries on a monthly basis. In the short-term, trash collection trucks or trucks designed for collection of recyclables could be retrofitted with a used oil collection tank or a rack on which to store containers of used oil (U.S. EPA 1989). In the short-term, this oil could then be exported off-site to a petroleum refinery for recycling or to a facility where it could undergo proper disposal.

Long-Term Options for Used Oil Treatment and Redistribution
Although the short-term oil recovery program would mitigate some potentially serious environmental hazards, it does little to promote the principles of
industrial ecology. Over the longer-term, the spent oil must be seen not as a waste but as a valuable resource. For this to happen, the Clark Development Corporation should develop an oil collection, treatment, and redistribution program (see Figure 5). We propose that the oil collection service transport collected oil to an onsite facility for treatment. Ideally, this facility would be located near or in conjunction with CSEZ’s 22-hectare petroleum, oil, and lubricant facility, which is currently under construction by the Subic Bay Metropolitan Authority and Coastal Subic Bay Terminal, Inc. Once completed, this fuel storage facility, which has a 570,000-barrel total capacity, will serve the fuel needs of aircraft at CSEZ International Airport. Co-location is also desirable since the used oil treatment and storage facility will be designed to prevent the migration of any oil that might spill onsite.

Once at the facility, the spent oil would undergo treatment that would allow it to be used as a fuel source (i.e., it would not undergo re-refining for reuse as a lubricant, which is an extensive process requiring full refinery capabilities). For most of the collected oil, a simple oil separation and storage apparatus should suffice (Morris 1993). If the used oil is emulsified, however, a more advanced system called “ultrafiltration” will be required. If high levels of metals or other contaminants are present, a chemical or reverse osmosis unit may be necessary. In both ultrafiltration and osmosis, the waste water that is removed during separation is clean enough to be used directly for gray water and could go to our proposed gray water collection area.

Once treated, the oil could be sold to CSEZ industries with oil boilers for use as a fuel source. The treated oil is actually a preferred fuel source for many industrial facilities. Used oil that has been treated is generally #4 grade oil. This is preferable for fueling purposes over #2 grade because it has a higher BTU value, and preferable over #6 grade oil because it is easier to handle. Many of the
industries in the CSEZ are potential candidates for this treated oil. Industries that are likely to have oil boilers include the Yokohama tire facility, tobacco facilities, plastics processors, metal products manufacturers, and the resort facilities. To further encourage used oil recovery, industries that participate in the oil collection program could receive the treated fuel oil at a reduced price.

Education Programs
A key component to the success of this used oil recovery program will be educating industry as well as households in order to gain participation. Used oil collection is relatively straightforward and, once educated, facilities should have little problem implementing collection practices. Most facilities would simply be encouraged to place oil receptacles under their machines, near areas of oil leakage. Households would be taught to collect used oil from their cars, using proper containers to avoid contamination from pre-used bottles or containers. To further minimize the likelihood of contamination of the used oil due to dirty containers, it might be practical for the oil company to provide collection containers to those participating in the program. This would also minimize the generation of additional hazardous waste, which would result from the disposal of oil collection containers.

SOLVENT RECYCLING
Industrial solvents include a wide variety of chemical compounds used in various manufacturing steps in the electronics, plastics, textiles, metal working, tool manufacture, rubber manufacture, and various other industries. Chlorinated and fluorinated solvents such as TCA, TCE, and CFCs are declining in use due to their ozone depleting properties. Industry must find technological solutions to questions of recyclability of new industrial solvents, such as the alcohol-based solvents methanol and acetone, which still pose environmental threats (Morris and Roberts 1993). Of the estimated 3.5 billion gallons per year of solvents produced in Canada and the U.S., almost two-thirds is consumed or is otherwise unavailable for reclamation. That leaves slightly more than 1 billion gallons per year that must be disposed of, most of which ends up being incinerated. Less than 10% of total annual production is refined and returned to commerce (Morris and Roberts 1993).

To reduce the toxic releases and to adhere to the eco-industrial park concept of closing loops in waste streams, there may be possibilities for centralized collection and recycling of industrial solvents at the CSEZ. The concept of encouraging a solvent recycler to locate in an eco-industrial park has been recommended by the Environmental Defense Fund for the Brownsville Eco-Industrial Park, in Brownsville, Texas/Matamoros, Mexico (Cohen-Rosenthal et al. 1996). Before describing the proposed flows of waste solvents in the CSEZ, the common methods of solvent recycling will be investigated.
Solvent Recycling Methods
The basic technology used to recycle solvents has not changed significantly in the last 50 years. The solvent-laden waste is boiled in a distillation unit to separate the solvent from the residual water and solid wastes. After vaporization, the gaseous solvents pass through a condenser to re-generate clean, recycled solvents. Distillation units use a batch system that handles one unit of solvent at a time (for instance, a 55 gallon drum) or a continuous feeding system that accepts a continuous flow of waste solvents without exchanging input batches or interrupting the recovery process (Coatings 1995). Distillation units can commonly handle a variety of solvents with boiling points ranging from low temperatures to solvents with boiling points well above 150°C (300°F) (Burke 1991).

The percentage of solvents that can be recovered from waste streams varies, although 70-80% is a reasonable industry average (U.S. EPA 1997). While 100% of the solvent could theoretically be recovered, it is not economically or logistically practical. As the clean solvent is boiled off, the residual liquid becomes increasingly thicker. In theory, all of the liquid solvent could be driven off with increasing heat inputs, until a solid, solvent-free residue remained. However, the energy inputs and the logistical problems of equipment cleaning and maintenance prevent complete solvent recovery (Coatings 1995).

One of the most significant benefits of recycling solvents is cost savings. There are two general options available for industrial solvent recycling: 1) installing an in-house recycling unit or 2) sending waste material to a large scale solvent recycling company. The EPA estimates that in-house solvent recycling machines run from $12,000 for a 20 gallon batch unit, to $15,000 for a continuous feed, closed-loop system accepting 55 gallon drum inputs (U.S. EPA 1996). While there is a cost to recycling solvents, in most cases it is less than the total cost of disposing waste solvents and buying virgin solvent inputs (Coatings 1995). Solvent recyclers typically pay for themselves within a few years of installation, or in some cases within months of installation, depending on the volumes of solvents recycled (Burke 1991).

Larger specialized solvent recycling facilities handle the majority of solvents recycled in the U.S. and Canada. Van Waters & Rogers (Kirkland, WA) and Ashland Chemical (Columbus, OH), two major global distributors of solvents, are also the main recycling collectors and consolidators in the United States. The companies were in a perfect position to develop “reverse distribution” because they already had the trucking and rail distribution infrastructure and expertise. Ashland and VW&R, however, do not perform any treatment themselves. Rather, they rely on contracts with treatment firms, including Laidlaw Environmental Services (Columbia, SC), Safety-Kleen (Elgin, IL), Southdown (Houston), and Chemical Waste Management (Oak Brook, IL) (Morris and Roberts 1993). Recycling companies have support equipment and mechanical technicians to overcome problems in the recycling process, and may prove more cost effective than on-site recyclers (U.S. EPA 1997). Recycling
companies can employ advanced technologies to increase recovery, including equipment to eliminate moisture in solvents and fractionation towers that separate blends of solvents to achieve higher purity. These larger solvent recycling facilities may cost upwards of $1 million (Coatings 1995).

A central solvent recycling facility may be the more cost-effective option. The eco-industrial park concept seeks to centralize infrastructure that not all industries could afford themselves, offering economic advantages due to economies of scale. Established solvent recycling companies can be encouraged to locate in the CSEZ, with a steady supply of incoming solvents as a positive economic incentive.

Solvent Flows
The flow diagram in Figure 6 represents a simple and theoretically cost-effective program to reduce overall solvent use. At the beginning of the flow cycle, the 13 electronics industrial facilities in the CDC use the “cleanest” (most pure) solvents, that may be transferred directly to other industries. This is a “downcycling” of solvent use from a high-grade application to lower-grade applications (Lowe et al. 1995). A similar scenario has been implemented by Ashland Chemical (Columbus, OH), one of the major global distributors, recycling collectors, and consolidators of solvents, and provider of ultrahigh-purity solvents to semiconductor manufacturers. The semiconductor production process leaves solvents very pure. Ashland Chemical recollects the nearly pure waste solvents, and resells the solvents to industrial customers at a reduced price (Morris and Roberts 1993). The eco-industrial park ideal suggested here would remove the solvent middleman.

Figure 6  Solvent Collection and Recycling
The low-grade waste solvents from the general industrial ecosystem can be transferred to a central solvent recycling facility. This centralized solvent recycling facility may be better suited to create transfers of used solvents to industries desiring alternatives to fossil fuels for combustion (Morris and Roberts 1993). Commonly, waste oil recyclers accept low-grade waste solvents. The low-grade industrial solvents could enter the larger waste oil recovery system described earlier in this document.

**Short-Term Possibilities for Solvent Recovery**

Using low-grade recovered solvents as a feedstock for fossil fuel boilers is a closed loop, although it is a transfer of a water emission to an air emission. However, there are emerging new technologies to recover low-grade solvents from residual wastes. For example, liquid nitrogen condensation and separation of pure solvent from the residual gaseous waste matrix can recover up to 99% of solvents in a waste stream, in pure form (Monroe 1997). Special facilities can distill various types of solvents, and regenerate the highest quality new solvents to return back to the industrial ecosystem. This reduction of virgin solvent inputs would represent a significant monetary savings, especially considering the volatility of the Asian financial markets, and the reliance on foreign trade for solvent chemicals.

**Long-Term Trends for Zero Solvent Waste**

The creation of a solvent recycling infrastructure is a short-term solution to the general problem of solvent use. Applying general industrial ecology principles may remove the need for solvent recycling, if industry moves towards zero solvent waste or zero solvent use technologies. Initiation of intensive internal solvent recycling programs, introduction of ozone based solvents, and implementation of water-based washing techniques would eventually reduce the feedstock to the solvent-recycling infrastructure. However, for the next 10-20 years, a solvent recycling facility is a viable option with available technology.

**COMPOSTING**

Composting would seem the ideal solution to utilizing some of the waste streams at the CSEZ, because it is a natural process, with which many people are already very familiar. Indeed there is already a small degree of “grasscycling” composting being carried out on the site by those who tend to the grounds (Magat 1998). We are therefore looking to expand this informal reprocessing into a more centralized system that can transform the waste from the tobacco industry, landscaping, greenhouses, and golf courses into valuable inputs to the system.

There are two tobacco companies operating at the CSEZ, and their waste is currently being transferred to a landfill. Special emphasis was placed on this industrial sector because the waste was similar enough to that being created by the greenhouses and golf courses that it would not have to be sorted prior to being composted.
Composting Technologies

A common approach to compost management is to install a centralized processing facility and so create an economy of scale through reducing labor costs, which on average make up 29% of the costs of a U.S. facility (Simson and Connelly 1994). However, due to the low labor costs in the Philippines, this economy of scale does not transfer. Therefore, it is more sensible to encourage smaller composting operations at each individual site. In addition, smaller facilities mitigate the major problem of compost odor. This occurs when the compost starts to decay anaerobically, rather than aerobically, which was a major problem at the Reuters’ Pembroke Pines facility (Waste Age 1993).

The most common technology utilized in solving odor problems is biofiltration. Biofiltration involves directing an air stream through a series of perforated pipes into a bed of organic media, which effectively removes the malodorous compounds. Costing between $1,000 and $2,000 per cubic yard of compost, plus $5-10 of annual operation and maintenance per cubic yard of compost, biofiltration may not be economically feasible (Aquino 1996). Again, this makes the larger facility a less attractive option.

The most suitable form of composting in the CSEZ would therefore be small-scale units associated with each facility. Not only would this reduce the potential problems of malodor, but it would cut down on transportation expenses. The tobacco companies could sell their unprocessed tobacco leaf waste or compost of the same to partner firms, as they do not have a direct use for compost.
Long-Term Flows
This investigation has been limited to a select few industries in the CSEZ that produce organic matter suitable for composting. In the future, many more organic residues can be composted, including by-products of wood manufacture, food-, paper-, textile-, cement- production, and construction/demolition (Cote et al. 1995). There are toxicity issues regarding composting that will have to be dealt with before implementing such a wide-ranging composting initiative. If municipal solid waste is to be composted, there needs to be very careful screening of inputs to prevent contamination from toxic wastes. This usually is combated by initial source separation, however, this is very labor intensive and adds dramatically to the costs of composting.

There are numerous instances where composting of low-grade paper, cotton, and other organics has demonstrated economic advantages over their use as raw material in marginal recycled products (Cote et al. 1994). However, until total costs of waste disposal are actually reflected in the tipping fees, composting of this kind may not be economically viable (Aquino 1996).

SCRAP TIRE RECYCLING
The industries and infrastructure development at the CSEZ present great opportunities for applying the principles of industrial ecology to “close the loop” on material flows associated with tire manufacturing within the industrial park. Finding uses for scrap tires promotes fundamental principles of industrial ecology such as recycling natural resources that are in limited supply (i.e., the large quantity of petroleum in tires), preserving the tire’s embedded energy, and turning a “waste” into an input. In addition, recycling tire wastes can prevent human health and safety hazards that are associated with the disposal of tires in landfills and in open stockpiles.

Tires are not well suited for landfill disposal because they tend to migrate to the top and can pierce the landfill cover. In addition, the open crevices in whole tires harbor pockets of landfill gas and make them an inefficient use of landfill space. For such reasons, 35 states in the U.S. have banned the disposal of whole tires in landfills (RMA 1998). At the same time, simply stockpiling scrap tires creates potential health hazards such as mosquito infestation, which can lead to the increased spread of disease, and risk of fire. Tire piles that catch fire can create significant water and air pollution and are difficult to extinguish.

Fortunately these hazards can be avoided because there are many opportunities for scrap tire reuse within the CSEZ. There are two main forms in which scrap tires can be reused. The first, and simpler option, is to find direct uses for whole scrap tires. The second and more cost-intensive reuse options require that the tires be “shredded” into rubber chips (generally two inches in diameter) or rubber crumb (approximately the consistency of small gravel or coarse sand).
Yokohama Tire Plant

The cornerstone of the proposed CSEZ tire reuse effort is the industrial park’s multinational Yokohama tire manufacturing facility. The four-acre Yokohama facility is located on 16.5 acres of land in Industrial Estate 5 of the CSEZ main zone. The plant’s design resembles the basic layout of a tire manufacturing plant, incorporating the four tire manufacturing processes – materials preparation, tire building, curing, and finishing. Yokohama’s system uses nine assembly lines capable of producing 51 different sizes of tires. The plant began operating on January 7, 1998. It currently generates 5,000 tires per day and will have manufactured approximately 1.2 million tires by the end of 1998. The Yokohama plant will be generating 10,000 tires per day (3.65 million tires per year) by 2001.

Like any tire manufacturing facility, the Yokohama plant produces rubber residues, which can be used as inputs to other processes. These residues include:

- pre-cured, off-specification rubber mixtures;
- pre-cured, off-specification tires (i.e., “green tires”);
- cured, off-specification tires.

Although there are opportunities to reuse off-specification rubber mixtures and green tires, the following recommendations focus on the use of cured, off-specification tires, because these residues present the greatest opportunity for cycle improvement at the CSEZ. Pre-cured off-specification rubber mixtures (usually in the form of rubber slabs) can generally not be recycled back into the tire manufacturing process because the mixture is not of high enough quality for reuse.

Figure 8 Rubber Flows
quality. These mixtures can however be used to make low-stress, low-dynamic rubber products such as floor mats and bumpers. If Yokohama does not have in-house capabilities to make such “side products,” efforts should be made to sell these mixtures to other rubber product manufacturing facilities. Green tires present more of a reuse problem because they are bound with fabrics, wires, and beads.

The Scrap Tire Management Council, a Washington D.C.-based trade association, estimates that for a given state-of-the-art tire manufacturing facility, between 3 and 4% of its tires will be off-specification. Up to one half of these off-specification tires are deemed so for cosmetic reasons and are still sold in many developing countries at reduced prices. Assuming Yokohama engages in such sales, one can still conclude that the Yokohama plant will generate between 18,000 and 24,000 scrap tires by the end of 1998, and once operating at full capacity, will generate between 56,750 and 75,000 scrap tires per year.

Other Sources
Next to the Yokohama facility, the next largest generator of scrap tires at the CSEZ is the airport. In addition to tires from the airport’s maintenance and transportation vehicles, the airplanes regularly replace their tires (Serungard 1998). Other sources of scrap tires within the CSEZ include gas stations and automotive repair facilities; vehicle fleets from infrastructure development efforts, transport of manufactured goods, and public transportation within the CSEZ; and residents’ vehicles. When all of these sources are accounted for, CSEZ emerges as a major source of scrap tires.

Short-Term Options for Scrap Tire Reuse
Whenever possible, the use of whole scrap tires should be encouraged. Some examples of possible uses for whole scrap tires at CSEZ include playground equipment such as tire swings and sandboxes (particularly the larger tires from trucks and airport vehicles) at the CSEZ-Philippines International School of Asia and the Grissom School. The resorts may also have playground facilities that could make use of these tires. Other uses for whole tires include roadway crash barriers (which would be particularly helpful at the CSEZ given the extensive on-going construction) and dock bumpers. While reusing whole scrap tires requires minimal transportation costs (short-range transportation within the CSEZ) and transaction costs, these uses will only account for a very small percentage of CSEZ’s scrap tire stock.

Long-Term Options for Tire Reuse
Given the magnitude of scrap tire outputs from the Yokohama facility, airport, and other facilities within the CSEZ, and the numerous uses for shredded tires within the site, investing in tire shedding equipment seems to make economic and environmental sense. Most large tire manufacturing facilities, such as Yokohama, do not actually shred their own tire scrap; rather, they enter into an agreement with a third party. Under such an arrangement, a third party “tire
shredder” would set up a facility near the Yokohama plant and enter into a contractual agreement to have rights to Yokohama’s scrap tires. The cost of very basic tire shedding machinery is $100,000 to $150,000; however, scrap tire experts state that such machines would not be able to handle the magnitude of tires generated at the CSEZ (Serungard 1998). The type of machine needed at the CSEZ would have operating costs in the range of a $400,000 to $700,000 a year. Given the diversity of shredded-tire markets at the CSEZ and throughout the Philippines, such an operation could be profitable. Following are brief discussions of some of the opportunities that exist at the CSEZ for using tire chips produced by a shredding facility.

Tire-Derived Fuel
Perhaps the best use of shredded tires is as fuel. Tires have 40% more energy value per pound than coal and an energy value roughly equal to that of oil (approximately 12,000 to 16,000 BTU per pound) (Goodyear 1998). Tires are a good fuel source because they are almost entirely made from petroleum. Most tires are made from synthetic rubber, which is produced from crude oil, carbon black, also produced from crude oil, petrochemicals, extender oils and organic fabric, produced from crude oil, and steel. At high temperatures, the steel in the tires oxidizes to produce 3,500 BTU per pound. Tires burn cleaner than coal, but some emissions will result from combustion and all facilities burning should test these emissions and put the appropriate control mechanisms in place.

Combustion facilities that currently use tire-derived fuel (TDF) include power plants, tire manufacturing facilities, and cement kilns. Because they operate at very high temperatures, cement kilns can thoroughly combust scrap tires. Also, cement production can utilize the iron oxide that results from the combustion of the steel contained in tires, steel belts, and beads. Not many facilities in the U.S. use tires because of the low cost of energy and low shredded tire disposal fees, but tires are widely used in Europe to fuel cement kilns. CSEZ currently has two cement batching plants: R.D. Policarpio & Co., Inc., and New Sampaguita Builders Construction, Inc..

Another longer-term option at the CSEZ is to retrofit the old 50 MW plant to be a TDF and waste-to-energy facility.

Golf Course Drainage
Tire chips can be used to achieve better drainage on the three CSEZ golf courses. As discussed in the water recycling portion of this paper, a layer of tire chips could be placed below the surface and above a liner on the golf courses to facilitate drainage and collection of the waste water leachate. Tire chips that are two inches in diameter have a hydrologic conductivity of approximately 1x10 cm/sec and provide an excellent medium for leachate collection (Waste Age 1996).
School Yard Groundcover
Tire chips can be used instead of gravel in playgrounds as a groundcover. They are safer than gravel in that they provide a softer cushion for children.

Construction Materials
Tire chips have many characteristics that make them excellent for use in construction projects. They can be used in place of many conventional construction materials such as sand, gravel, stone, and clean fill. Tire chips are one-third to one-half as heavy as gravel, are sound thermal insulators, and provide good drainage (generally 10 to 100 times better than many soils). Many contractors use tire chips as lightweight fill for retaining wall backfill, as insulating layers, as daily landfill cover material, for leachate collection aggregate, septic fill aggregate, and as roadbed material. Given the magnitude of infrastructure and facility construction underway at the CSEZ, these projects could serve as a great receptor for a substantial volume of tire chips (Powell 1996).

Tire Wire Recycling
In addition to the rubber, the steel used to make tire belts and beads is also a valuable residue. About 10% by weight of a scrap tire is steel wire. Many tire-shredding facilities recover this material because it is high-quality, high-carbon, high-strength steel (EPA 1989). One problem associated with wire recovery is that it can be difficult to detach all the rubber from the wire; however, many shredding facilities are improving their ability to do this (Goodyear 1998). Scafforms International Manufacturing and Trading Corporation, which is located in CSEZ, manufactures steel scaffolding and accessories for export. This facility may have use for these high-quality steel residues in its manufacturing process. If not, the tire shredding facility should still recover this steel and try to export it to a steel mill in the Philippines.

CONCLUSION
In recalling the initial representation of the disjointed existence of industrial residents at the CSEZ, the intricacy of the possible materials and energy flows model is impressive and overwhelming.

When coupled with the many possibilities for exchange that remain to be integrated into this model, it is easy to see how the execution of such a plan can get very complicated. However, if planned well, the evolution of the CSEZ industrial park into an eco-industrial park can be a rewarding process with successful results.

In order to undertake the conversion of the CSEZ, there are a few major decisions to be made about how best to organize and develop the project. Will the Clark Development Corporation carry the project or follow the example set by Kalundborg, allowing the actors to take ownership? Who will pay for capital expenditure and maintenance costs? These are questions that must be resolved as the project progresses.
Figure 9 CDC Eco-Industrial Park
The question of initiative and capital funds for the energy cascading piping systems and centralized processing units (CPUs), i.e., the solvent and oil recycling and waste water treatment facilities, will have to be decided fairly early on. Some options include:

- Invite new firms to come in and take over the central processing roles, asking fair market value for their services;
- Allow the Clark Development Corporation to develop and take over management of the CPU services, levying fees for per unit usage of the services, and covering the capital expenditures for installment from resident fees. The same could be true of the energy cascading system;
- Look to public entities for support. Given that clean water and energy provisions are responsibilities of public utilities, they gain from the efficiency and treatment measures adopted by an industrial ecology effort (Kalundborg received such support from the local government);
- Designate responsibility to firms for raising capital for the construction of the energy transport mechanisms and facilities using a variety of methods for payment of services including tradable permits.

Regardless of the path taken, there are two steps that, if taken from the start, could prove beneficial throughout the development of the EIP: 1) provide education on applied industrial ecology and 2) solicit input and participation from member firms.

The provision of educational materials and training sessions on industrial ecology concepts and applicable tools is the first step to ensure that an EIP can be established. If the resident firms do not understand and espouse the larger goals of sustainability and the means to achieve them, they are more likely to reject the effort.

At present, many companies fail to realize that their wastes are marketable (Dwortzan 1998). Research conducted at Cornell University shows that when employees are encouraged to participate in the larger industrial ecology effort and are educated about the goals and potential outcomes, the companies have achieved reductions in materials consumption up to three to four times higher than without taking this step (Cohen-Rosenthal 1996).

Once education on the basics of sustainability and industrial ecology concepts has been provided, the CDC would do well to make information available about more advanced industrial ecology concepts and tools such as design for environment (DFE), total quality management (TQM), sustainable architecture and design, and life-cycle analysis (LCA). The educational materials could be distributed, or an educational center could be established where participants would have access to reference materials and be invited to attend training sessions. Of particular relevance to an educational effort at the CSEZ is the presence of the "Private-Sector Involvement in Environmental Manage-
ment” project in the Philippines (Hamner 1998). This project, sponsored by the United Nations Development Programme, and the first of its kind in Southeast Asia, includes training in industrial ecology concepts and a pilot industrial ecology project (Hamner 1998).

Once the CSEZ employees have a general understanding of industrial ecology, they should be surveyed to determine their level of interest, environmental and economic priorities, ideas for development, potential for exchange, and level of commitment to the project, i.e., if they would be willing to serve on any committees or educational teams. This information will serve as an excellent base from which to start the planning process and project implementation. In addition, should any conflicts arise over decisions about the larger park, the CDC can reference the information provided via the surveys.

**Barriers to Success**

It is instructive to point out that there are several challenges to successful EIP development:

- There are risks associated with the failure of a supplier or receiver within the park;
- Neighbors to the EIP can impact the environmental resources that the industrial ecology model seeks to protect;
- Firms rarely keep close track of their metabolism of materials and energy. This is information that is required in evaluating potential for park-wide efforts as well as bilateral agreements. Therefore, firms often have to invest in information gathering, which can be a costly and time-consuming process;
- When firms have the information, they are often unwilling to share it for fear of losing competitive advantage.

Recognizing that these barriers exist is half the battle to overcoming them. Many of them can be surmounted with time as relationships based on trust, understanding, and mutual benefits are built.

**Long-Term Goals**

The CDC will want to consider a few long-term goals during the planning process and throughout the development of the EIP. One such consideration will be whether the CDC and CSEZ partners will target “filler” industries for location at the park. This would be an effort to tighten the closure on the EIP loop to move toward the idealistic goal of zero waste production. Partner firms would be invited to identify their remaining waste streams from which an analysis could be conducted to highlight industries that would be a good “match” for receiving the byproducts.

Targeted industries often play the role of the “decomposer” in the industrial ecosystem (Lowe et al. 1995). In a natural ecosystem, decomposing organisms take the final key step in “closing the loop” by breaking down the waste materials from other production processes and then discarding them in a
useable, available medium to be consumed by another actor for the next cycle of production.

This process of niche-filling will be ongoing because, again, like natural ecosystems, markets are dynamic even when they are stable (Lowe et al. 1995). In addition, it is important that once the target industries have been identified, the CDC should screen specific firms for quality assurance purposes. Basically, the CDC would seek firms that embrace the larger ecological goals of the park, and would be willing to work with on-site firms in developing materials exchange agreements. This suggests that the CDC would have its choice of several firms from a given industry. While this may not be the case at first, it is likely that the reputation accompanying EIP status will bring more than enough willing potential partners to the table.

In addition to the long-term goal of targeting industries, and those proposed throughout this paper, the CSEZ may want to consider greater incorporation of on-site service industries in materials and energy exchange, and the advancement of industrial ecology practices within firms, using the tools discussed in the educational proposal.

The president of the Philippines has hailed the CSEZ as the nation’s development leader. The conversion of the park to an economically and environmentally sustainable EIP will only elevate its visibility and leadership role throughout the world. Already, the Chinese government has shown interest in the CSEZ as a potential model for brownfields redevelopment. All of the evidence presented here points to the conclusion that the CSEZ has great potential to become the “Kalundborg of the Developing World.”

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