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ABSTRACT  
Eco-industrial parks (EIPs) have recently appeared as an innovative approach to addressing modern business concerns in the face of increased environmental degradation. From the most complex (Kalundborg) all the way down to two-company linkages, the implementation of this concept is becoming increasingly widespread around the world. The focus of this paper is to illustrate one such linkage in Montville, Connecticut, established by AES Corporation, a global power company, and Stone Container, a major paper company. The first section of this paper will describe the natural environmental and local industrial components of the area to provide some background on the Montville area. Following will be a description of the innovative AES/Stone Container linkage. A section outlining several scenarios for the development of the region within the conceptual framework of eco-industrial activity and a section on policy implications will conclude the paper.

THE TOWN OF MONTVILLE

Town Profile  
The town of Montville incorporates the villages of Uncasville, Mohegan, Chesterfield, and Oakdale in southeastern Connecticut. Montville lies west of the Thames River, about 5 miles from Long Island Sound, 2 miles south of Norwich and 1.5 miles north of New London. The town was founded in 1786 and has an approximate population of 16,750 people on 43.9 square miles of land. It is governed under a Mayoral/Town Council system. Montville is mostly rural and suburban, although a number of industrial plants and state and federal installations are located along the Thames River. Upland areas along the river, at one time cultivated, have become overgrown with woods and scrub.

Resources  
Sand and gravel, used in the production of concrete, are valuable natural resources in eastern Connecticut. The largest of these glacial deposits are located in the terraces along the Thames River. Clayey till, which compacts well, is used for fill in highway construction. Agriculturally, the land is fertile because of the eolian material (windblown sediment) that covers much of the quadrangle. This material is easily worked, holds water fairly well, and is relatively free of stones. Some swamps in the area have been converted to cranberry bogs.
and some of the swamp muck has been used as fertilizer for lawns and gardens. Because of the shallow stream gradients in Montville, hydroelectric power cannot be produced. Adequate supplies of water are kept in storage reservoirs and settling basins for industrial use along many of the upland streams. There is also quite an extensive system of springs and wells in the Montville area.

INTRODUCTION TO INDUSTRY IN THE MONTVILLE REGION
Following is a description of some major and minor companies located in the Montville region. These companies will be discussed further in the presentation of three possible scenarios for the establishment of an EIP in the Montville area.

AES Corporation
AES Corporation is a multinational independent power producer. The corporation puts together financing for power plants, has them built by outside contractors and then owns and operates them. AES currently retains primary ownership of 12 plants and has interests in 21 others, located around the world (Salpukas 1997). AES Corporation’s mission is to provide clean, safe, low-cost electricity (Cropper 1993). All of their six U.S. plants run on coal and are designed either to meet the needs of independent customers or to serve as supplements to a utility.

AES has a reputation for being among the most environmentally conscientious power producers in the United States. By developing highly specialized, clean coal burning technologies, AES has demonstrated its dedication to minimizing the emissions traditionally associated with coal plants, particularly sulfur and particulate emissions. In addition to carefully monitoring their emissions, the company has a forestation project designed to offset the potential exacerbation of global warming created by the emissions associated with all of the company’s power plants. As a result of this effort, over 52 million trees will be planted in Guatemala (AES Corporation 1996).

In addition to being concerned with minimizing emissions, AES is also concerned with minimizing the amount of energy wasted in the electricity-producing process. As a result, six of the U.S.-based AES power plants are cogenerators. A portion of each plant’s “waste” steam, is redirected to a local, symbiotic company, to be used in its manufacturing processes.
AES Thames Montville, Connecticut Plant
At its Montville facility, AES Thames produces 181 MW/hour of electricity, which is sold to the neighboring Northeast Utilities plant. The AES plant imports coal from West Virginia. The coal is burned using the aforementioned clean coal technology. At the start of the process, the coal is crushed and mixed with limestone and injected into the boiler (see Figure 1). As the coal burns, the sulfur dioxide is absorbed by the limestone and the ash, and hot gases produced flow to the top of the combustion chamber. These ashes and hot gases flow out

Figure 1  AES Thames Cogeneration Plant

the top of the combustor into the Hot Cyclone. Partially burned fuel and ash are re-injected into the combustor, in order to get maximum fuel efficiency. After full combustion, the hot exhaust passes over banks of water and steam piping in the Convective Pass to produce superheated steam.

Ash taken from the Cyclone heats the final reheated and superheated steam and then returns to the combustor. This superheat steam is then directed to a turbine, which is propelled to produce electricity. The exhaust gas, which by now has lost most of its heat, is routed through fabric-filter baghouses, which remove and collect the particulates and fly ash for disposal.

At the end of the coal burning process, AES is left with several waste products. The remaining fly ash, which is composed of limestone and particulate matter, is typically used as landfill for post-mining applications. AES is also left with non-contact cooling water which has warmed by 17°C before it is returned to the adjoining river. Levels of air emissions associated with electricity production are
high, especially sulfur dioxide (SO$_2$) emissions, and therefore have to be carefully monitored. Some of the excess steam produced is routed as fuel to the Stone Container Corporation’s manufacturing processes. However, there still remains steam that could be used for cogeneration.

**Stone Container Corporation**

Stone Container Corporation (SCC) is a major, multinational paper company with annual sales in excess of $5 billion (authors’ note: Stone Container Corporation was recently purchased by Jefferson-Smurfit and renamed Smurfit-Stone). The corporation produces a variety of paper and corrugated cardboard box products as well as pulp for market. At a few facilities SCC also produces lumber and wood chips. SCC operates over 200 facilities in the United States, Europe, Australia, Asia, and Central and South America.

SCC emphasizes environmental, health, and safety issues and places them high on its list of priorities. In its forestry practices, SCC is committed to Best Management Practices (BMPs) on its timber land and it has established the Landowner Assistance Program to help landowners in the southeastern United States learn about them as well.

SCC is committed to environmental stewardship in its plant processes. In the corporation’s environmental report, it calculates that approximately one third of the fibers used in its products are from pre-used sources, making SCC, in its estimation, the world’s largest consumer of pre-used paper products (SCC 1997). In a joint venture with WMX, the world’s largest collector of recycled paper, SCC established PRI, a shipping corporation that supplies recycled materials to SCC and other corporations around the world.

SCC not only uses recycled fiber for its products, but also developed a product take-back policy, collecting its post-use products from customers for recycling. SCC already has 100 closed loops in place and plans to collect over 85 million pounds of old product from its customers in 1997. In addition to using recycled paper products for its manufacturing process, SCC practices on-site cogeneration, reusing boiler steam to produce electricity and to provide heat for the pulp cooking process as well (SCC 1996).

Between 1991 and 1995, SCC affected a 19% corporation wide decrease in energy use, 11% of which was due to a reduction in fossil fuel use. In addition to reducing energy use, SCC is also moving toward a significant reduction in its plants’ already low air emissions and has a goal of zero waste-water discharge.

Despite SCC’s active environmental programs, a number of grassroots organizations claim that the bottom line is of much greater importance to the company. For example, La Sierra, an environmental action group, professes that Stone Forest Industries, a subsidiary of SCC, is selling timber in Colorado and elsewhere below cost. According to this group, SCC is also currently in violation of anti-pollution laws in fifteen states (Boulder Community Network 1997).
Stone Container Corporation: Montville, Connecticut Plant
SCC’s Montville operation produces low-grade corrugated cardboard, which serves as filler for cardboard box walls. This plant uses 100% recycled materials in its manufacturing processes. When the used paper products arrive on site, they are converted into pulp by a hydropulper. Through a subsequent set of filtering processes, the “waste” materials are removed and the pulp is dried. The pulp is then passed through a refinery, screens, and sand traps, where further impurities are removed. Once cleaned, the pulp is pressed out flat on the fourdrinier to be heat dried. When the process is completed, the cardboard is sold to the Rand Whitney Corporation as a filler for box shells.

Not all of the post-use materials that are imported into the plant by truck and rail to be used in the cardboard production are reusable. SCC is forced to deal with a significant amount of refuse, removed through the filtering process, including plastics, paper, Styrofoam, glass, and baling wire. In total, 25 tons/day of plastics and 15 tons/day of metals are recovered. These materials pose an important problem, as the corporation is unable to recycle much of this waste due to its heterogeneous nature and is currently paying to dispose of it at a landfill.

Another environmental issue facing the Montville plant is the large amount of water required for the pulping process. Three types of water management problems result from the process: diversion, non-contact cooling water, and storm water discharge. The plant also has to monitor nitrous oxide (NOX), sulfur dioxide (SO2) and volatile organic compound (VOC) emissions associated with an on-site boiler that produces some of the energy to fuel operations, although these emissions are generally low.

Dow Chemical Company
The Dow Chemical Company is the fifth largest chemical company in the world. Dow produces plastics, chemicals, agricultural products, and consumer goods, reaping annual sales of more than $20 billion. With close to 40,000 employees and 94 manufacturing sites in 30 countries, Dow is a powerful multinational corporation with a great potential for environmental impact. In 1994 alone, for example, Dow generated over 1,500 tons of global emissions of EPA priority compounds (Dow Chemical Co. 1996).

Dow operates a sizable production plant on the east bank of the Thames River across from AES and Stone Container. Originally built in 1952 to manufacture Styron, the plant has constantly expanded over the last several decades to accommodate Styrofoam, butadiene latex, and Magnum ABS resin production. The energy and raw material inputs were not made available for this study. However, the multi-product facility generates several residual air, water, and solid waste streams. These include acrylic acid, acrylitrile, butadiene, chloroethane, dichlorethane, ethlybenzene, and styrene. In addition, the company operates a solid waste landfill on the site to handle 620 cubic yards of latex residuals annually (Dow Chemical Co. 1995). The landfilling operation...
includes mixing the latex with soil to speed biodegradation and covering the mixture with grass seed, mulch, fertilizer, and limestone. Although the Dow residuals and operations hold great potential for an area EIP, Jack Tamborra, the government affairs manager for the Northeast region states, “While it appears to be of some academic interest, we as a company are not willing to participate” (Tamborra 1997). Dow has published several pro-environment marketing brochures for programs at the corporate and local level. However, it appears that the company is not interested in eco-industrial park development at the present time. Therefore, we will not consider its potential contribution to the area EIP.

**Rand-Whitney Corporation**
Rand-Whitney is about 1.5 miles away from AES and Stone Container in Montville. Similar to Stone, it is a cardboard processing plant, producing a finer grade of cardboard box. Rand-Whitney produces the outer cardboard walls for Stone Container products. Its flows are similar, namely cardboard pulp and a lot of water to produce its product. Rand recycles its water from the sewage treatment plant.

**Northeast Utilities**
Northeast Utilities (NU) owns and operates a 600 MW power plant 1.5 miles from the AES-Thames cogeneration plant. This NU plant operates on oil and natural gas. In addition to its own electricity production, Northeast Utilities has a contract to buy 181 MW from AES.

**The Montville Sewage Treatment Plant**
The Montville Sewage Treatment Plant is just a few hundred yards away from AES. It treats wastewater for the surrounding area, including the town of Montville, the Mohegan Sun Casino and Rand-Whitney. It has a total budget of $2 million per year, and 11 full time employees.

The plant uses activated biological processes to remove pathogens and break down the sewage it receives. Large electrical-powered turbine blowers are used at this site to aerate the water. The water is then sent through settling tanks to remove the solid waste. The sludge produced is 5% solids, with no heavy metals or other hazardous contaminants. It is sent offsite for further drying and incineration.

**Faria Corporation**
Faria Corporation is a marine gauge manufacturing company. It processes raw metal using injection molding and stamping to manufacture parts. These parts are then painted in closed and filtered machines and assembled. Faria is a zero discharge facility, which means it has no air or water waste. However, there is a variety of solid waste which is dealt with in various ways. The metal scrap from the stamping process is sold to a local scrap dealer. Paint rags and carbon filters from the painting step are incinerated. Corrugated cardboard from packaging is recycled at Stone Container Corporation. Plastic resins are reground and
recycled. Wooden pallets from shipments are sold to a local business that remakes and resells them. Office papers are recycled and all other trash (mostly office waste) is landfilled.

Faria buys its electricity from the grid. The representatives were unable to provide a specific use amount, but indicated that their manufacturing processes are energy intensive. They heat the plant with steam produced on site.

EXISTING CONNECTIONS BETWEEN MONTVILLE INDUSTRIES

Input-Output Flows
Input-output flows were calculated from data provided by Kevin Pearce at AES-Thames, Lou Armstrong at Stone Container, and the Montville Sewage Treatment Plant. Flows were quantified to obtain a better understanding of the exchange of materials in this industrial area. With this knowledge the potential for linkages between industries as well as between flows is examined. All figures were converted into a standard metric (tons per day) for the purposes of comparability and consistency (see Figure 2).

Major waste streams from each of the three industries examined will be discussed briefly here. These are the streams that will be addressed in the three scenarios proposed later in this paper. Stone Container produces a solid waste stream of 25 tons of mixed plastics, which currently is being landfilled. Of these
25 tons of plastic, 20 tons can be used commercially in a variety of different applications. Stone Container also produces approximately 15 tons of scrap metal, glass, Styrofoam, dirt, gravel, and other miscellaneous materials. These materials are also currently being landfilled and are not, at this time, commercially reusable.

AES-Thames, being an electricity producer, generates a large quantity of air emissions including $SO_x$ and $NO_x$. In addition to these emissions, AES produces approximately 420 tons of coal ash per day. Currently this ash is sent back to coal mines in Pennsylvania for reclamation. Of this 420 tons, 60%, or 252 tons per day, is commercially viable as various forms of fly ash. AES also produces vast quantities of steam. Sixty-five percent of the heat in this steam is lost to the stack and to the Thames River. Twelve hundred tons of steam per day is piped to Stone Container as part of a cogenerative process. The additional heat produced each day is not being utilized; rather it is condensed, then released into the Thames River. Non-contact cooling water flows through the AES plant in extremely large volumes. This water is released into the river at an average rate of approximately 43,200 tons per day.

The Montville Sewage Treatment Plant is a municipal plant that processes sewage waste at a rate of 1,200 tons of input per day. Of this, 60 tons is solid material (sludge) and the additional 1,140 tons per day is treated water. Following are the calculated material flows for Stone Container Corporation, AES, and the sewage treatment plant.

Table I  Stone Container Material Flows

<table>
<thead>
<tr>
<th>INPUTS</th>
<th></th>
<th>OUTPUTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Materials</td>
<td>Old Corrugated Cardboard (OCC) = 540 tons/day</td>
<td>OCC = 500 tons/day</td>
</tr>
<tr>
<td>Energy</td>
<td>Electricity Needs = 8 MW/hour x 24 hours/day = 192 MW/day</td>
<td></td>
</tr>
<tr>
<td>AES Steam Supplement = 1.5 MW/hour of energy x 24 hours/day = 36 MW/day; 36 MW/day x 10,000 lbs of steam/day = 360,000 lbs of steam/day; 360,000 lbs of steam/ day x 1 ton/2000 lbs = 180 tons/day</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid Residuals</td>
<td>Mixed Plastics = 25 tons/day; 20 tons of which are recoverable</td>
<td></td>
</tr>
<tr>
<td>Scrap Metal = 15 tons/day; none of which is currently usable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liquid Residuals</td>
<td>Trace amounts of chlorine and sulfur</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No water waste due to operation as a closed system</td>
<td></td>
</tr>
<tr>
<td>Gaseous Residuals – Regulated Amounts</td>
<td>NO$_x$ = 0.14 tons/day</td>
<td></td>
</tr>
<tr>
<td>SO$_2$ = 0.14 tons/day</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VOCs = 0.14 tons/day</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO = 0.14 tons/day</td>
<td></td>
<td></td>
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</tbody>
</table>
### Table 2  AES-Thames Material Flows

<table>
<thead>
<tr>
<th>INPUTS</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Raw Materials</strong></td>
<td>Coal = 2,143 tons/day</td>
<td>Limestone = 219 tons/day</td>
</tr>
<tr>
<td></td>
<td>Non-contact cooling water = $1.08 \times 10^8$ gallons/day $\times 8$ lbs/gallon $\times$ 1 ton/2,000 lbs = 432,000 tons/day</td>
<td></td>
</tr>
<tr>
<td><strong>Energy</strong></td>
<td>517 MW/hour based on 35% efficiency of 181 MW/hour $\times$ 24 hours/day = 12,408 MW/day</td>
<td></td>
</tr>
<tr>
<td><strong>OUTPUTS</strong></td>
<td>Energy = 181 MW/hour $\times$ 24 hours/day = 4,344 MW/day</td>
<td>Fly-ash = 420 tons/day</td>
</tr>
<tr>
<td><strong>Solid Residuals</strong></td>
<td>Water (non-contact cooling, etc.) = $1.10 \times 10^8$ gallons/day $\times 8$ lbs/gallon $\times$ 1 ton/2,000 lbs = 440,000 tons/day</td>
<td>Steam = 10,000 lbs/MW $\times$ 4,344 MW/day $\times$ 1 ton/2,000 lbs = 21,720 tons/day</td>
</tr>
<tr>
<td></td>
<td>14,118 tons/day at 65% efficiency is lost to the stack and to the non-contact cooling water</td>
<td>1,200 tons/day is given to Stone Container</td>
</tr>
<tr>
<td></td>
<td>720 tons/day is excess that could potentially be collected</td>
<td></td>
</tr>
<tr>
<td><strong>Gaseous Residuals</strong></td>
<td>$CO_2$ = 0.96 tons/day</td>
<td>$NO_x$ = 1.38 tons/day</td>
</tr>
<tr>
<td></td>
<td>$SO_x$ = 5.76 tons/day</td>
<td></td>
</tr>
</tbody>
</table>

### Table 3  Montville Sewage Treatment Plant Material Flows

<table>
<thead>
<tr>
<th>INPUTS</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sewage</td>
<td>$300,000$ gallons/day $\times 8$ lbs/gallon $\times$ 1 ton/2,000 lbs = 1,200 tons/day</td>
<td></td>
</tr>
<tr>
<td>Energy</td>
<td>$20,000$/month (@ ~ $0.09$/KW-hour)</td>
<td></td>
</tr>
<tr>
<td><strong>OUTPUTS</strong></td>
<td>Solid Residue = 5% of 1,200 tons /day = 60 tons/day</td>
<td>27.4 tons/day incinerated based on $60$/ton tipping fee (info from SCC) and a $600,000$/year disposal bill</td>
</tr>
<tr>
<td></td>
<td>$32.6$ tons/day must be landfilled</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Liquid Residues Treated Water = 1,140 tons/day</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gaseous Residues None reported</td>
<td></td>
</tr>
</tbody>
</table>
SCENARIOS FOR THE DEVELOPMENT OF AN EIP
This section is dedicated to the group’s recommendations as to how the above mentioned materials and energy flows can be improved to increase efficiency. Scenario 1 will focus on improvements that can be made with minimal effort while Scenario 2 will propose more wide-reaching changes. Scenario 3 will propose a more radical solution to the current waste problems facing the industries of the Montville region.

Scenario 1: Improvements on the current system
This first scenario proposes changes that could be made without bringing in or setting up any new business in the area.

Triangulation Improvements
A current practice of Stone Container is triangulation. This involves taking its finished product of cardboard boxes, shipping it to a packing plant for the customer’s product, then taking the boxed items and bringing them to the retailer. From the retailer, a truck then picks up the used cardboard and brings it back to the plant to be recycled. This type of system forms an efficient triangle, and could be expanded for the area.

Rand-Whitney and SCC Waste Recycling Improvements
Currently, Rand-Whitney is producing 40 tons/day of Old Corrugated Cardboard (OCC). Due to incineration costs, the OCC is being landfilled since it is $20/ton cheaper to dispose of it in this manner. Rand cannot use this OCC since it is producing the outer sides of cardboard boxes, and appearance and texture count in its final product. However, Stone Container’s product (the inside filler of cardboard boxes) is much rougher, and it can potentially use this OCC in its product. This system would be cheap and environmentally efficient, and would benefit both Rand-Whitney and Stone Container. Stone would need to invest in some new machinery to process and clean up the OCC to create a material that it can use.

AES Waste Heat Use Improvements
AES currently has two large volumes of heat that are being lost to the environment: the low-pressure steam that emerges from its turbines, and the cooling water that is deposited in the river (see Table 4).

The current contracted average shows what AES is producing right now. As seen in the table there are 720 tons/day of excess low-pressure steam that are not being utilized. This steam could be used for increased district heating or on-site electricity production. District heating uses a central source to produce steam or hot water that is then pumped to nearby homes and businesses. The AES steam is well within the parameters needed for district heating and could be used for this purpose. Pipes would be necessary to distribute it to the area. There are several businesses in the area that would be good targets for this: Faria, which is already heating with steam produced on the premises, Rand-Whitney,
SCC, the Sewage Treatment Plant, and the Mohegan Sun Casino. The other option for the low-pressure steam is to use it to produce energy at other businesses. The potential energy output from this steam is shown in the last row of Table 4, and ranges from 21.6 MW/day to 23.0 MW/day with the existing set-up. Other local businesses could utilize this potential energy source in the same way as SCC to produce cheap electricity. Potential users would be the Sewage Treatment Plant, Faria, Rand-Whitney, and the Mohegan Sun Casino.

**AES Cooling Water Improvements**

AES uses approximately 75,000 gal/hr of cooling water. This is equivalent to 820 million BTUs/hour being lost to the river. AES designed the plant under a National Pollution Discharge Elimination System (NPDES) permit that limited the average temperature range of the water discharged to prevent heat pollution to the river. This range is currently 18ºC in the summer and 20ºC in the winter. This means that the cooling water is not as readily usable as the steam. However, with some changes to the AES cooling system, this could become a very efficient way to produce hot water for district heating. A system designed to use less water, and to recycle it through a closed loop would be very practical for this district heating. Currently, the coolant water is also treated to minimize chlorine pollution. A closed loop would prevent the need for this type of treatment as well.

**Scenario 2**

The goal of this scenario is to find appropriate uses for the large waste streams produced by these industries. Scenario 2 actively seeks to introduce new industries and technologies and to promote new material linkages. It allows the eco-industrial park relationship to be strengthened while still maintaining a sense of independence and flexibility. By being proactive and testing the frontiers of these particular industries, Scenario 2 may also be able to prohibit the dangerous concept of “lock-in,” where if one company fails, the entire system fails. This type of approach is crucial to ensuring the overall success of the EIP in the long term.

<table>
<thead>
<tr>
<th>Table 4</th>
<th>AES Steam Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Current Contracted Average</td>
</tr>
<tr>
<td>Energy Production (MW/hour)</td>
<td>181</td>
</tr>
<tr>
<td>Total Steam Produced (tons/day)</td>
<td>21,720</td>
</tr>
<tr>
<td>Potential Excess Steam (tons/day)</td>
<td>720</td>
</tr>
<tr>
<td>Potential Energy (MW/hour)</td>
<td>0.90</td>
</tr>
</tbody>
</table>
Development of Commercial Use of the Coal-Ash Produced by AES

Combustion of coal produces large volumes of waste. One component of this is coal ash, which includes fly ash, bottom ash, flue gas de-sulferization sludge, and fluidized bed combustion wastes. Coal burning plants in the U.S. are producing around 75 million tons of ash annually. Currently, only about 24% of this ash is being utilized, with the remaining amount being landfilled (West Virginia University 1996). Since coal is a nationally produced energy source and prices are relatively stable, coal ash as a waste stream is not likely to be reduced any time in the near future. Due to these large volumes of coal ash, a number of alternatives to landfilling the waste have been devised. These alternatives range from simple applications to complex commercial processes that regard coal-ash as a raw material resource. AES is producing 420 tons of coal ash a day – a huge potential resource.

One of the simplest uses for coal ash is reclaiming the mines from which the coal was originally mined. The ash is alkaline (due to the limestone residue from burning) and so neutralizes the natural acidity of old mine sites. The ash can also increase a plant’s available water, reduce the toxicity of trace metals, and allow for better aeration of the soil. Vegetation in mine areas can be maintained for decades on ash-treated soils, where plants have failed on conventionally treated soils (Geonews 1996). AES is currently using its ash to reclaim mine sites in Pennsylvania. However, its contract to ship the ash ends in three years. Other alternatives within the Montville area might prove more economically and environmentally feasible.

Many structural uses for coal ash have been developed. Most use fly ash, which is one of the finer particulates of coal ash. Fly ash comprises approxi-
approximately 60% of the total coal ash from a coal power plant. The exact percentage varies, depending on the type of burn mechanisms employed, the type of coal burned, and the efficiency of the plant. From 1990-1996, approximately 20 patents for fly ash products were filed each year, and many others are under investigation (Western Ash Company 1996). Fill uses for fly ash, with no additional processing necessary, include flowable fill, structural fill, road base, asphalt filler, ice control applications, and blasting grit. An example of the commercial use is ReUse Technologies, which markets fly ash under the brand names of EZ Fill (with kiln lime for cementous properties) and Xcel Fill (without kiln lime added) (ReUse Technologies 1996). Other uses for fly ash are cement/ceramic applications, wallboard, gypsum, and other assorted applications. These require some form of processing and additional materials to make the ash into a usable material.

Most of the new technologies are in the construction and agricultural industries. Some examples include a process by Argonne, which developed a chemically bonded ceramic technology which forms a material from ash that is “inexpensive, dense, leach-resistant, and stronger than concrete materials” (Tech Transfer Highlights website 1996). Another option is to use the ash as a fertilizer. ReUse Technologies markets a pelletized ash under the trademark BUCKSHOT®, for use as an agricultural fertilizer (ReUse Technologies 1996). A third example is using ash as a substitute for gypsum. Currently, USG Corporation is opening a new plant to market Sheetrock®, which uses coal ash as its main material source. The plant will be able to make 700 million square feet of wallboard per year. USG plans to have the plant replace one that is making wallboard out of conventionally mined gypsum. Lastly, cement is another potential fly ash product.

Another option for combining sludge with coal ash has been developed by Minergy, a company based in Wisconsin. They blend the raw materials and then mineralize them in a high-temperature rotary kiln to produce Durolite. Durolite is a strong, lightweight aggregate which is superior to natural aggregates for structural concrete applications. It is also finding a market in insulating concrete, as fire-resistant material filler, and as a landscape ground cover. The process has the added benefit of yielding recoverable thermal energy, which is used to provide steam and electricity. Minergy is currently using 150,000 tons of ash and sludge annually (Minergy 1996).

The introduction of a cement company to the area is one of the more promising options. Fly ash is already composed of the same materials as cement, but in different ratios. Combining fly ash and lime will produce a material analogous to Portland cement. Most cement production utilizing coal ash has shale, limestone, fly ash, and water as its raw materials. Montville and the surrounding towns have a number of small gravel quarries which could be a source of shale and gravel fill. Additional limestone could be brought in with AES’s shipments.
One example of the use of ash in cement production is Roanoke Cement Company, which currently uses about 42,000 tons of coal ash from nine different sources. The equipment and material streams used are similar to those in the cement industry (West Virginia University 1996). One of the benefits of a local cement company would be transportation cost savings. The cement industry is regional in nature, with most of its costs in shipping. The majority of cement produced is shipped less than 300 miles to its end use. By having all of the material sources for the company in the area, monetary and environmental costs would be reduced.

The cement industry is a growing market. Since 1980, production has steadily increased, and in 1995 approximately 86 million metric tons of cement were used in the US, with 13.8 million metric tons imported to meet domestic need (Cement Industry 1996). Connecticut alone had a growth of more than 5% in the cement industry (The Monitor 1997). Utilizing coal ash as a raw material for cement would save the energy involved in mining and processing raw material streams. The American Coal Ash Association estimates that substituting coal ash for cement materials reduces C02 emissions by 4-5 million tons per year (Cement Industry 1996). The potential impact from less mining and transportation, as well as the good market growth, make this an attractive option for Montville.

Another promising idea for the use of coal ash is to combine it with another waste stream in the Montville area. The Sewage Treatment plant has a large volume of sludge that currently is incinerated at a cost of $600,000 to $800,000 per year. There are several new technologies that use a combination of coal ash and sludge. One is the production of soil. The potential market for topsoil and other garden fertilizers is huge. In 1994, the US spent over $25 billion on gardening and landscaping.

Currently, some states are using municipal wastewater sludge as a fertilizer for agricultural soils. By using a mixture of coal ash and sludge, the soils formed are found to have a greater amount of organic material and nutrients available to the plants, are pH balanced, well drained, and are able to retain their minerals with less leachability. Studies by West Virginia University have shown a much higher success rate with apple orchards using the sludge-ash mixture than many of the local, naturally occurring soils. They have also found that the toxic trace elements that can be found in coal ash (such as boron, molybdenum, selenium, and arsenic) are stabilized by the sludge, and that there was much less leaching than in raw coal ash (West Virginia University 1996). One process, ASH-IT, by the University of Alaska, produces a stable, highly fertile soil with no odor in the production process. These soil products are targeted at crops that need a high amount of calcium and sulfur, such as peanuts and soybeans.
Waste Plastics Management

One waste stream that Stone Container and Rand-Whitney share is waste plastic that is removed from recycled cardboard during processing. Each facility produces about 20 tons daily, for a yearly total of 14,240 tons. Currently, this plastic is being landfilled but other options are available. If it were to be incinerated in a conventional waste-for-energy situation, it could potentially produce a vast amount of energy. This is not being done now because the tipping fees at incinerators are about $20 more per ton than the rate at landfill sites.

Another possibility for handling the plastic remains is to convert them into plasma gas using a plasma waste converter (PWC). A PWC is an electrically driven machine that provides an intense field of radiant energy that causes the dissociation of the molecular bonds of solid, liquid, and gaseous compounds or materials of both hazardous and non-hazardous wastes. The molecules of the waste material are separated into their elemental atomic components and then reformed into recoverable, non-hazardous commodity products ready for commercial use. The elemental components of the feedstock can be recovered in different phases:

1. Synthetic gas (Plasma Converted Gas, PCG) that rises to the top of the chamber;
2. Inorganic, glass-like silicates, that collect above the metals in the chamber;
3. Liquid metallic elements, which collect at the base of the chamber.

The PWC requires electricity to operate, but for each unit of electricity used to process waste, approximately four units of energy is recovered in the form of PCG gas. In addition, the PWC reduces the volume of waste by 300 times.

In terms of managing the metal waste resulting from Stone Container’s operations, the value of the metals will vary greatly with the composition of the scrap going into the PWC. In general, the metals would be passed through the PWC and the impurities and toxins would be plasmatized and collected as PCG. The metals would be recovered as a conglomerate block, clean of impurities and ready to sell to a metal recycler.

The plastics could easily be converted into PCG gas. PCG gas is made up of carbon, hydrogen, and oxygen, just like fossil fuels. Consequently, it can be used as feedstock to produce more polymers or as a clean fuel for a fuel cell or some type of electricity-producing turbine. According to StarTech Environmental Corporation, 25 tons of plastics would produce approximately 25 tons of PCG (StarTech 1997). The exact amount/ton of waste injected and composition of the PCG produced is dependent on the actual composites of these waste polymers. However, PCG has a current market value of 3.7¢ per thousand cubic feet, and therefore the PWC would turn this polymer waste into a salable, reusable product. In order to determine how much PCG would be produced from SCC’s plastics waste, a test must be run on the waste source at a cost of approximately $20,000. Unless toxics are present in the waste stream the PWC will probably be too expensive for SCC for at least the next 5 years.
There is another, less capital intensive, more economically viable option for dealing with the plastics wastes. Atlon Labs of Acton, Massachusetts specializes in taking unwanted plastics and developing a product from them. The plastic waste from Stone Container is of a poor quality, being a mixture of many different types of plastics combined with contaminants of wood pulp and water. Atlon has experimented with samples of the plastic from Stone Container and found that by mixing it with a plastic waste stream of a known consistency, they are able to form a feedstock that is usable. Atlon uses a process that takes the feedstock at room temperature, heats it to molten temperatures, and then uses an injection molding process to make its products. Most of what would be made are high volume products such as pallets, curbing, and patio blocks. Atlon Labs operates independently and has a viable market niche.

Atlon has extensive experience in the waste disposal business. It operates “nodes” of business around the country where there are waste streams that can be used. They capitalize on a cheap abundant raw material (most businesses either give the Atlon facilities the plastics for free or even pay them to take it at a cheaper cost than it would cost them to dispose of it, and use a process that allows them to recover contaminated materials). Currently Atlon is very interested in using the plastic from SCC and Rand-Whitney, but it needs to expand its capacity to be able to deal with the volume coming to its facilities.
also needs to find a consistent source of waste plastic with a known consistency, such as milk jugs or soda bottles. One possible such source might be from Montville and local communities. Currently the Groton Recycling Center, which sorts the recyclables for Montville and 10 other local communities, has a curbside recycling program that produces approximately 400 tons of #2 plastics and 100 tons of #1 plastics each year. The Mohegan Sun uses an independent contractor, but also could be a potential source of recyclable plastic. While these sources clearly will not provide all of the plastic necessary, it would be one way of helping to close the loop in this area.

**Introduction of Fuel Cells**

Since both Northeast Utilities and AES-Thames are energy producers, it is crucial that they stay abreast of changes in the electricity industry. At the forefront of this industry is the fuel cell, an alternative form of electricity production. A fuel cell operates similarly to a battery in that it supplies electricity by combining hydrogen and oxygen electrochemically, without combustion. In this process, the hydrogen is usually produced through a steam-reforming fossil fuel process and the oxygen is usually derived from the air. However, unlike a battery, the fuel cell does not need to be recharged, only refueled.

The cell consists of two electrodes (an anode and a cathode) sandwiched around a particular type of electrolyte. As oxygen passes over one electrode, hydrogen passes over the other to produce electricity, water, and heat. Natural gas is the most commonly used fuel. Fuel cells are classified by the type of electrolyte that they use. Common types include: alkaline (AFC), phosphoric acid (PAFC), Proton Exchange Membrane (PEM), Molten carbonate (MCFC), and Solid Oxide (SOFC).

Fuel cells can be used for a variety of purposes: they can be used as a prime power supply, as an interruptible power supply, or as a cogeneration system. The best potential application seems to involve cogeneration where the fuel cell is used to offset conventional energy consumption by reclaiming waste heat, as in the preheating of boiler feedwater.

Perhaps the greatest benefit of fuel cells, however, is their low environmental impact. Since an electrochemical process, rather than a combustion process, is used to produce electricity, emissions are generally much cleaner and more benign. The main “waste” products are potable water and CO₂. Natural gas utilization and efficiency can be greatly improved, especially when coupled with cogeneration and heat recovery, lowering the amount of energy needed to produce electricity.

As new technologies find alternative fuels to natural gas, consumption of fossil fuels can be reduced. One particularly interesting alternative that is being researched is the use of methane gas piped from landfills as the source of fuel for the cell. The methane produced by a local composting company and by the
Montville Landfill, located only a few miles away, could be used as a source of fuel (see Figure 5). This would enable AES or Northeast Utilities to tap into a reservoir that is not currently being exploited, lessening reliance on fossil fuels extracted from virgin territories. Also, the potable water produced by the fuel cell could be piped into the existing water line infrastructure. This new source of water could help to alleviate water shortage problems.

**Scenario 3: Brewery**

*Craft Brewing*

The opportunities for increased efficiency in material and energy flows discussed in Scenario 1 and Scenario 2 have laid the foundation for Scenario 3. Scenario 3 offers a more intensive illustration of how we can develop an EIP in Montville (see Figure 6). The soil that the proposed EIP has the potential to produce, the open land in the area, and the excess energy in the form of steam create perfect conditions for the establishment of a brewery. Just how a brewery might be established and sustained in Montville will be examined below.
A craft brewer, who is designated for production below 15,000 barrels a year, would be ideal for the Montville area. Craft brewers represent only 1.5% of the U.S. beer market, but have enjoyed a 30-40% growth in production per year over the last five years (Samuel Adams 1996). These small volume, high quality beers have enjoyed tremendous popularity, lending confidence to the viability of establishing such an enterprise. Furthermore, the characteristic niche marketing of such businesses could allow a Montville brewery to promote the environmental sensitivity of the beer and maintain a small distribution area.

Malt, hops, water, and yeast are the necessary ingredients to make beer. We will avoid what are called “adjuncts.” These are starches and other preservatives such as potassium metabisulfite, sodium metabisulfite, and ascorbic acid that make beer lighter and give it a longer shelf life. Not using adjuncts keeps the material flows simple and meets the German Reinheitsgebot of 1516, the highest purity standard in the brewing industry.

The plan for the craft brewery relies on 5 acres of local hop production and 157 acres of local barley production. These will produce enough raw materials with existing resources to produce 15,000 barrels a year. Additionally, the yeast will be cultured in the facility on a growing medium. It is our belief that area soil conditions ameliorated by EIP produced soil and brewery compost from the brewing process will provide an excellent nutrient base for the crops. Furthermore, we feel the growing season is adequate, as the location is further south than the most famous hop regions in the world.
Beer Production
The fundamental processes of beer production are malting, brewing, fermenting, and packaging (see Figure 7). In the malting process, barley is soaked in water and then the partially sprouted grain is kiln-dried and roasted, forming malt (Samuel Adams 1996). The malt is then combined with water, heated, and strained. The resulting substance (commonly called the “wort”) is then boiled with hops and strained again. These two steps, which have been greatly simplified here, comprise what is actually considered the brewing process. The fermentation process follows, which consists of the addition of yeast to metabolize the sugars in the mixture, forming alcohol and CO₂. The yeast is recovered after its use and can be re-used up to ten times (United Nations 1996). At this stage the beer is ready for any number of packaging alternatives.

Environmental Concerns
Figure 8 illustrates a simplified resource flow of a brewing facility. The material usage obviously varies by specific product types and production technologies and techniques. The small quantities of residuals generated by our brewery make it difficult to conceptualize tremendous environmental impact. However, there are some environmental impacts associated with brewing. Some of these include: surface water pollution or depletion, ground water pollution or depletion, global warming (CO₂ emissions), acid rain and other air pollutants (NOx and SO₂), and waste disposal.
Our EIP scenario addresses each of these categories. To begin, air pollution concerns (which typically are associated with gas or oil boilers) could be alleviated through the use of steam as power for the majority of the operation. With our target of 15,000 barrels, the steam requirements could easily be met by AES. It is perhaps helpful to keep in mind that the plan is for a brewery without a sophisticated heat recovery system. Heat-consuming processes like boiling, sterilization, and bottle washing could be minimized by good insulation, maintenance, and/or a steam condensate return system (United Nations 1996). A steam condensate return system would make heat available for other heating processes such as cleaning and pre-heating of fluids before the boiling process.

Additional energy requirements could be met by the recovery of ammonia from the composting of spent grains. The composting operation could also be skipped altogether with the conversion of spent grains into methane. This type of technology is already in place at the brewing giant Beijing Brewery which produces its steam needs through methane-powered boilers (Gertler and Ehrenfeld 1996). There is also the potential for some alcohol-bearing waste streams to be distilled into ethanol, which obviously has fuel potential. While these gas conversion techniques may have resulting air pollution impacts, the potential for resource use savings is enormous.

It is difficult to discern if water consumption would be an issue. With the abundance of ground water and the capacity of the Montville Sewage Treatment Plant to perform secondary treatment, it seems likely that the supply would be adequate if augmented by on-site treatment to raise water to brewing standards. Pollution issues could be addressed by the combined treatment of brewery and municipal wastewater that can be beneficial for both parties on economic and environmental fronts. One reason for this is the biodegradable

![Figure 8](https://example.com/figure8.png)  
**Figure 8**  Simplified Resource Flow of Brewing Operations  (United Nations 1996)
organic compounds in brewery wastewater that are conducive to the removal of nitrogen through common de-nitrification processes.

Another synergistic benefit of the combined water treatment is the biological treatment processes that are enhanced by the warm brewery water (United Nations 1996). This is particularly important in colder areas such as Connecticut. Wastewater problems may also be alleviated through land application. Where proper soil and climatic conditions exist, land application could be an extremely attractive solution. The crops grown with such substances are typically subject to regulatory requirements.

Ground water pollution from breweries is typically associated with the storage of fuels and cleaners in underground tanks. Where tanks are necessary, above ground tanks will be used. Obviously, the demand for fuel tanks will be minimal, due to our energy recovery strategies. Where cleaner use is necessary, we will use Iodophor™ an iodine based cleaner engineered to avoid the problems associated with chlorine (Havnold and Nickerson 1993).

A very interesting concept particularly useful to breweries is to address the wastewater and waste disposal issues at the same time through the use of wastewater materials recovery and the subsequent composting of suitable materials. As demonstrated by the Anheuser-Busch brewery in Baldwinsville, New York, composting reduces the amount of brewery waste that must be landfilled by 80 to 90% (Beers and Getz 1992). This facility, which produces 7 million barrels annually, generates 30,000 dry pounds of bio-solids a day, equivalent to about 120,000 pounds of wet sludge. The composting process is quite simple and has yielded some astonishing results. From 1989-1991 an annual average of 24,633 cubic yards of sludge was composted, yielding an average of 28,766 cubic yards of compost. This has resulted in some $1.1 million per year in tipping-fee savings.

Obviously, the craft brewery would operate on a different scale, generating only about 13.42 cubic yards of compost annually. But this is only the beginning of the potential efficiencies of the EIP. Inexpensive plastic beverage containers and shipping pallets are a very realistic possibility considering the area’s plastic surplus and the resulting product possibilities from Atlon Labs. An array of cardboard containers could also be produced easily by Stone Container and Rand-Whitney. To reduce needed landfill space and resource use, returnable bottles are also common to brewery plans. This idea, however, brings up some interesting environmental trade-offs. Bottle-washing operations use large amounts of energy, water, and cleaners. The use of non-renewable containers obviously lessens these environmental burdens while increasing others. One redeeming quality of washing operations is that some of the commonly recovered materials such as paper pulp, cigarette butts, aluminum, and plastics have the potential to be recycled or used in our many waste recovery scenarios.
Policy and Regulatory Concerns
There are many aspects of local and federal policy that must be considered in coordinating an EIP in the Montville area. To begin, the Montville Environmental and Economic Coalition should be involved in the development of the park from the outset. This group, which formed due to the recent growth in the area spurred by the Mohegan Sun Casino, is the embodiment of local environmental concerns. The extent of its power is not clear. However, operating without communication with the Montville Environmental and Economic Coalition is not advisable.

On the federal level, the Resource Conservation and Recovery Act (RCRA) also poses some interesting questions about the possibility of an EIP becoming operational. The confusing language of RCRA does not make clear what materials can be reused, recycled, or reclaimed. It is generally believed that RCRA does not allow for much innovation in this area. Another difficult aspect of RCRA is the regulation of hazardous materials. Several hazardous and potentially hazardous materials that are mentioned as material flows in this report have the potential to create enormous permitting and paperwork requirements. When planning for the use of hazardous materials in the EIP it will be advisable to work closely with counsel and regulators to determine precisely what is permissible under the law. It is encouraging to note that some regulatory burdens have been lifted for industrial ecology scenarios that are beneficial and pose no significant threat to the environment (Beers and Getz 1992).

The last regulatory concern is single-medium permitting. Clearly there are many economic and environmental reasons why an EIP would want to be regulated as one entity. However, there are liability concerns for companies associated in this way. Several legal questions remain unanswered regarding the liability of companies that are regulated as a single unit when one or more companies engage in an illegal activity.

The government has and will have a tremendous role in the future of eco-industrial parks. The regulatory structure as it stands now is the largest obstacle for the development of such initiatives. More flexibility will have to be integrated into the law-making process not only in the U.S. but around the world. To find the systemic solutions that are consistent with solving environmental problems, new directions in policy will have to be charted. It is with this in mind that the researchers of the Montville EIP call for communication among all EIP stakeholders and a commitment to EIP research domestically and internationally in order to ensure the vitality of this innovative concept.

Anheuser-Busch Composting
The Anheuser-Busch brewery in Baldwinsville, New York has turned to composting as an innovative way to deal with the large amounts of solid waste typical of brewing operations. With land application limited because of the harsh winter weather, incineration less desirable because of air pollution concerns, and the high cost of land-filling, the brewery composts its residual sludge in an attempt to avoid economic costs and recover some of the nutrient and mineral value of the solids. The composting operation mixes de-wated sludge cake, sawdust, and recycled compost in 12 bays measuring 5.5' x 6.6' x 216'. A hydraulic blender mixes the compost in each bay and discharges 12 feet of finished compost daily.

The environmentally and economically sound composting process was developed by International Process Systems of Lebanon, Connecticut. The process uses daily mixing, and exacting aeration and temperature controls, to achieve the extraordinary results. A bio-filter of compost, sawdust, and coarse sand is used to absorb the composting gaseous by-products to avoid odor problems for the nearby residential community. Temperature control is achieved by automatic thermocouples attached to the side walls of the bays. The programmable sensors maintain the 55-60ºC temperature by the cycling of aeration fans.

In a collaborative partnership with NYNEX, the brewery has also been experimenting with using old telephone books as a replacement for the sawdust. Additionally, the recent addition of an anaerobic pretreatment facility that is supposed to reduce brewery waste solids by 33% has led to exploration of use of the excess composting capacity. Beechwood chips and packaging materials are some of the experimental materials. Success with these materials would make the composting even more attractive in terms of EIP possibilities.
REFERENCES
   ben.boulder.co.us:80/environment/earthfirst/LaSierra/Stonecol.htm.
Dow Chemical Co. 1995. Allyn’s Point Pamphlet. Gales Ferry, CT.
Dow Chemical Co. 1996. *Continuing the Responsible Care Journey*. Progress on Environment, Health and
   Safety.
   may96/coalash.html
   February/March.
Havnold, A. and G. B. Nickerson, 1993. Factors affecting hop production, hop quality and brewer prefer-
   process.html#INTRO.
   communication.
   Programme, v. 106.
   coalshtechbrief.html.

FURTHER READING
   experience*. Cornell Center for the Environment.
   16:36-39.