Closing Waste Loops

An Economic Comparison of MSW Treatment Systems in Sweden

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Abstract:

Because human societies have not closed solid waste loops in the production and consumption of goods, methods of solid waste treatment are still necessary. In this work the author examines two modern methods of municipal solid waste (MSW) treatment as employed in Sweden. These methods are waste treatment in a bioreactor cell and MSW incineration. The investigation analyzes the critical economic components of each method—arguing that the method of MSW treatment that mimics nature’s more closed ecological systems is not only a more sustainable method of solid waste treatment, it is also more cost-effective. The components examined in this investigation are construction and operational costs of each treatment method, process by-product treatment costs, post-closure bioreactor cell care costs, and revenues received through the sale of energy obtained through each treatment system. The sites used in this comparison are that of Filborna, in Helsingborg, Sweden, operated by the NSR Company to that of general numbers for a newly constructed facility in Sweden incinerating approximately 200,000 tons of waste per year. Results from this economic comparison reveal that the cost for treating MSW in a landfill bioreactor cell are 89 SEK/ton with the employment of a vegetation filter for leachate purification purposed, and 101 SEK/ton if leachates are treated by a conventional wastewater treatment facility. The investigation also demonstrates that MSW wastes treated by incineration costs are 335 SEK/ton—substantially greater than that of treatment in a bioreactor cell. Further findings reveal that the significant gains from the employment of a vegetation filter are not the revenues received from the sale of the biomass fuel source, but rather the cost savings of the leachate purification.
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1. Introduction

1.1 Market System Inadequacies

Modern economics can be viewed as the manner in which social systems allocate scarce natural resources from ecological systems. But the manner in which societies partake in this allocation has been of increasing-concern in recent decades. Modern methods of resource utilization are neither efficient, nor equitable. These inadequacies, coupled with recent economic growth in many countries, are showing there are few signs that human societies are turning toward a more sustainable, “steady state” economic system based on economic development instead of unsustainable growth (Daly 1996).

In addition to an economic system based on this unsustainable growth and mass resource exploitation, we also have a system that produces colossal quantities of wastes. These wastes, or so-called “negative externalities,” are the side effects of a production and consumption system that effect a third party in a negative manner (Pearce et al. 1994). This third party in many cases are almost all facets of human society, being adversely affected by such environmental problems as groundwater and soil contamination, air pollution, global warming, and anthropogenic eutrophication. But from a theoretical point of view, the ability of natural ecosystems to absorb these wastes are scarce (Pearce et al. 1994); so with this understanding, in recent years we have seen increasingly-effective mechanisms for treating these by-products of our present economic paradigm. Today, “the aim of waste treatment has switched from purely disposal to more and more recovery” (Bramryd 1997-98). Most modern waste treatment systems have progressed from the “open dump” of the not so distant past, to that of highly-sophisticated facilities, often with by-product recovery systems in place.

Because solid waste streams impact so many aspects of human society, it is of the utmost importance to follow them closely to help create new methods and policies that reduce their negative environmental impacts upon society. But, this paper is not a survey of the methods of solid waste management that exist throughout the globe today, but rather an examination

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1 A Steady-State Economy (SSE) is a system based not on quantitative physical growth and the increased utilization of energy/matter throughput, but one based on qualitative development and technical progress based on increases in durability and repairability (Daly 1996).
of current methods of treating solid wastes are optimal from both ecological and economic perspectives.

1.2 EU Waste Management Activities
The European Union is one body that has been active in recent years in directing waste management policies in a more sustainable direction for member-countries. Within this arena, stricter implementation of regulations for treatment facilities, increased recycling rates, extended producer responsibility, and the promotion of life-cycle assessment (LCA) approaches in the manufacture goods have all been actively pursued (Engblom et al. 1999). These efforts culminated in 1996 when these EU waste management principles were formally made into a general waste strategy. This European Union strategy now focuses on a preferred hierarchy of waste management operations that includes:

- **Prevention of Waste**
- **Recycling and Reuse**
- **Optimum Final Disposal and Improved Monitoring**


1.3 Swedish Waste Policy Efforts
One country that must abide by European Union regulatory actions is Sweden. Sweden became an EU member-country in 1995, and has been an integral player within the organization in formulating more-effective waste management policy. On a national front, “Swedish waste management policy has developed considerably since the 60s as a result of greater waste volumes, increases in difficult to handle wastes, greater public awareness of environmental problems, and stricter policy requirements on working environments (Hogland et al. 1997). As a result of these changes, Swedish waste management policy has also become increasingly stringent in recent decades. In fact, it can be argued that, “methods of waste management in Sweden are now more advanced than those encountered in the EU” (Hogland et al. 1997). Differing only somewhat from European Union priorities, Swedish waste management focuses on the following priorities:
• Reduction in the exploitation of resources and minimisation of waste
• Increases in material recovery
• Energy extraction of waste and other biological treatment techniques
• Conventional Landfilling


With these political efforts, national statistics are now showing that general waste management priorities are gradually being realized in this country of approximately nine million inhabitants. In Sweden, overall waste collected in 1999 decreased slightly over the previous year from 3,865,000 tons in 1998 to 3,794,000 tons in 1999 (RVF 2000). This collection decrease is at the same time that biological treatment and incineration of waste have increased, while the amount of conventional landfilling has demonstrated a steady decrease. Swedish waste treatment percentages for 1999 are as follows:

- Recycling 28.8%
- Biological Treatment 8.4%
- Incineration 38.0%
- Landfilling 24.3%
- Hazardous Waste 0.5%


1.4 Waste Management Policy Instruments
As can be seen, political systems play a meaningful role in directing waste management policies in particular directions. One of the economic tools that have been used by the Swedish establishment in steering national waste management along more sustainable route are taxes. To advance the use of methods that employ energy recovery from waste over conventional treatment methods, there now exists a 250 SEK/ton tax on solid waste that is landfilled in Sweden. This tax, which went into effect January 2000, is the primary mechanism that is driving Swedish waste practices today to one dominated by solid waste incineration.

1.5 Treatment Techniques in Sweden
With the previously mentioned policy goals in mind, waste incineration, now approaching 40%, is the predominant method of treatment for municipal solid waste (MSW) employed in Sweden. But MSW incineration is not the only large-scale option of waste management in
effectively extracting useful and reusable components back into human societies. An alternative method of waste treatment to incineration is that of treatment of waste in landfill bioreactor cells. Many mistake waste handling in a bioreactor cell to that of conventional landfills. But solid waste treatment in bioreactor cells differs from conventional landfills from the perspective that bioreactor cells employ measures to actively-stabilize the waste contained in the cell. Today, this is carried out through the addition of moisture into the cell to enhance “microbial processes under anaerobic conditions to accelerate the degradation of refuse” (Sullivan 2000). This moisture addition, often by mixing MSWs with water during final waste deposition in the cell, or irrigating the top of the cell area with water or previously filtered cell leachates, stimulates waste decomposition while at the same time accelerating methane gas production within the deposition cell.

Additionally, other techniques, such as mechanical waste shredding, solid waste mixing, and/or the introduction of microbial cultures within the waste are also options that intensifies the waste degradation processes and accelerate the cell stability period (Bramryd 2000).

1.6 Aims and Hypothesis

Because human societies have not completely closed the waste loops in the production and consumption of goods and materials, systems of solid waste management are still essential. In recent years in Sweden there has been the increasing utilization of waste treatment through incineration. But is this movement the correct course? Shouldn’t an optimal solid waste treatment system, and ultimately a more sustainable one, be based on methods that resemble natural ecological processes as closely as possible? The intention of this work is to examine two solid waste treatment methods as they exist in Sweden, and compare both the actual approaches utilized in treating MSW with them while analyzing the significant economic components of each of them. The argument of this study is that the bioreactor cell approach to waste handling, one in which more fully resembles nature’s closed-systems, is not only a more sustainable technique than that of MSW incineration, but is also a more cost-effective way to deal with municipal solid waste streams. Economic comparisons for this study will be made between a particular treatment facility located in the southern region of Sweden operated by Northwestern Scania Solid Waste and Recycling Company (NSR), called Filborna, to that of general information gathered for a newly-constructed incineration facility operating in Sweden. The significant economic components that will be investigated for each
treatment system will be general facility construction and operating costs, energy or fuel sale revenues, bioreactor post-closure costs and avoided costs using alternative treatment techniques. Because of uncertainties, this study will not consider the components of land acquisition costs and biomass ash values.

2. Theoretical Framework of Waste Treatment Systems

2.1 Bioreactor Description

2.1.1 Filborna

NSR’s landfill bioreactor cell facility serves the 217,272 inhabitants of six municipalities located in the northwestern part of the province of Skåne (Bengtsson 2000a). The solid wastes for this area have been shipped to this facility since the early 1950s. But NSR has established and operated a bioreactor cell project since 1989, which has now given it significant experience in this method of solid waste treatment. In 1999, NSR’s bioreactor cell received 107,256 tons (Bengtsson 2000a) of solid waste. In addition to the bioreactor cell, NSR also operates numerous recycling and composting centers located around the region along with a separate bioreactor for separated organic wastes.

2.1.2 Causal Loop Diagrams (CLDs)

An effective way to understand the waste management systems compared in this investigation is through the use of Causal Loop Diagrams (CLDs). The CLD is a method of displaying a system, in this case a production system and a waste treatment system, as a “group of interacting, interrelated, or interdependent components that form a complex and unified whole” (Anderson et al. 1997). Also important for the comprehension of these interactions, the components in these systems have relationships between them, denoted by either a “+” or “-” next to each variable. A “+” indicates that there is a positive relationship between the two components. For example, if the amount of waste increases, then the requirement for additional waste handling facilities would also increase. Conversely, the “-” next to the variable expresses that there is an opposite relationship between the two. A simple illustration of this association would be an increase in the utilization of energy for waste treatment would cause a decrease in the reliance on other forms of energy.
2.1.3 Grasping Bioreactor Cell Interactions

The CLD for waste treatment in a bioreactor cell is actually comprised of two main systems (see Figure 1). The first system (right side of model) is the flow to convert resources to usable goods and energy for human society, while the second system (left side) is the method of solid waste treatment for the discards of these production and consumption systems.

One can begin by viewing the interactions at upper right hand portion of the above figure where the aggregate resource supply is equal to the inputs of both renewable and non-renewable resources. From this resource supply, the conversion to new products and usable energy occur. Following the arrow to the left, the energy in turn can also be used to assist in the production system in the transformation of resources into new products. In the manufacturing process, portions of these resources become waste, and are transferred to the waste treatment system. Conversely, because there has been progress in recent decades, a
portion of production wastes are now brought back into the resources supply through recycling and deposit-refund programs. The parts that don’t become waste or are brought back into the resource chain are then made into usable products. These products are then acquired and ultimately consumed by human societies. It is here that these products either become waste or are reintroduced at the consumer level back into the resource supply chain also through recycling processes. One can alternatively observe that an increase in human consumption has an adverse effect back on the supply of aggregate resources, most notably, non-renewable resources. It is at this point that we move into the second system in the CLD, the system of solid waste handling in a bioreactor cell.

With the deposition of MSW in a properly lined bioreactor cell (see Figure 2), increased microbial processes occur. These processes produce mainly methane gas (CH₄) and carbon dioxide (CO₂), which are collected in a simple pipe extraction system and transported to a regulation station nearby the facility. The methane can then be sold and used as a fuel for heat and electricity production, or as a storable motor fuel for running such things as equipment and vehicles.

Following the arrow around to the far left of the CLD, the decomposition of wastes also generates cell leachates that are captured year round in a large containment system, where they are stored for redistribution. The benefits of this system are that “pollutants, such as heavy metals, are captured in the fermentation residue and are left in the landfill” (Bramryd 1997-98), thus isolating them from reintroduction back into the environment. Bioreactor cell leachates then can be transferred from these storage basins in warmer months (mid-May through mid-October in southern Sweden) to an adjacently grown energy crop-vegetation filter, such as

Figure 2: Bioreactor Cell

The above Figure shows the basic makeup of the bioreactor cell. Reactor gases and leachates are accumulate through their appropriate collection systems, while the solid wastes are effectively immobilized within the cell parameters.

Source: Bramryd 1997-98
willow (*Salix viminalis*), for both crop fertilization and leachate purification purposes. Depending on the species of biomass planted, the mature crop then can be harvested after a period of time where it can be used, like the methane gas from the cell, as a renewable fuel in the energy system for production of heat and/or electricity. Furthermore, with the utilization of both the biomass crop and the methane produced in the bioreactor, one can see that there would be an overall added dividend of a reduced reliance on other fuel sources for energy production needs.

Recent Swedish studies that have analyzed the effects of utilizing both municipal wastewater and landfill leachates have shown promising results. It has been demonstrated that when irrigated with these waste products energy crop stem growth rates are three-times higher than non-irrigated crops (Wennman 1999), and there is a 50-percent growth rate increase over bioenergy crops that have been commercially fertilized (Börjesson 1999). These elevated growth rates are a result of an optimal supply of both nutrients in the wastewater and moisture supply to the crop.

There is the additional component that must be accounted for with this system; this factor is the production of ash created in the burning of the biomass. This process by-product can be viewed as an expense or potential revenue within this system. On the positive side, the ash can be reintroduced back into the forest ecosystem as a soil stabilizer/fertilizer (upper-right corner of CLD). Such an element has the benefits of reducing the need for commercially produced fertilizers, offsetting the energy needed to produce these products, while at the same time reducing both space and costs for deposition of the ash back in a permanent containment system, such as a bioreactor cell.

One can see with the use of the bioreactor treatment system that the potential to reintroduce both energy, in the form of methane gas, and nutrients, in the form of leachate occur while, as mentioned, permanently and effectively binding the unwanted waste components in the bioreactor cell. Furthermore, the utilization of the gases and leachate also create accelerated settling in the bioreactor cells (Pacey et al. 2000, Sullivan 2000, Bramryd 1997-98), which allow for further waste deposition in the cell on top of the already stabilized rest product.
2.2 Incineration Description

2.2.1 Incineration in Sweden

As discussed, MSW incineration is a method of waste management that has seen steady increases in Sweden in recent years. This expansion is due to both national and European Union goals of decreasing waste, especially organic, to landfills. Today, there are 22 incineration facilities in Sweden that convert solid wastes into a usable energy source. Of these facilities, 95% of the energy is used for district heating production—providing Sweden with 10% of its total district heating needs (RVF 1998), and the remaining 5% is for electricity production. In 1999, 1,440,000 tons of waste was incinerated in Sweden (RVF 2000). From this quantity of waste, 6.4 TWh of hot water and electricity were generated (RVF 2000).

2.2.2 Understanding Incineration Systems Interactions

The incineration of municipal solid waste can be viewed as two interacting systems much in the same manner as treatment in a bioreactor cell. As can be seen in the right portion of

*Figure 3: MSW Incineration Systems Interactions*

Similar to Figure 1, this CLD shows the relationship between the system of goods production and MSW treatment by incineration. With this system the heat production can be introduced back into the energy system—usually for district heating purposes, but unlike bioreactor cell treatment, the nutrient chains are not reintroduced back into the agricultural sector because they are locked with the ash and slag by-products.
Figure 3, the societal generation of waste through the production and consumption of goods ultimately becomes a waste product, which are then transported to a centrally-located incineration facility. These solid wastes are then burned at temperatures as high as 850 degrees Celsius (Rylander 1997). From this process large quantities of heat are produced; this energy then can be reintroduced back into society as energy in the form of district heating or electricity.

With the incineration of MSWs there are also emissions that escape to the atmosphere (lower left side of CLD). In recent years due to increased EU regulations on incineration facilities, emissions of heavy metals, dioxins dust, along with sulfur dioxides and nitrous oxides have decreased from the burning MSW from 55- to 99-percent (Rylander 1997) if calculated per cubic meter of emitted fluegas. But although there have been drastic decreases in emission releases from MSW incineration, it still remains a significant air pollution concern.

The expenditures for updating older Swedish incineration facilities have not been cheap either. It has been estimated that these more stringent regulations have meant an additional 840 million SEK investment for incineration facility operators throughout the country (Rylander 1997). Even with this enormous investment, 1,550 tons of nitrogen oxides, 1,160 tons of sulfur oxides, and 133 tons of Lead were released into the atmosphere by Swedish incineration facilities in 1995 (Rylander 1997).

As can be viewed on the left portion of the causal loop diagram, another component of this system that remains an environmental concern is the disposal of the by-products that remains after the incineration process. Incineration leaves approximately 20-percent by weight toxic slag and 5-percent toxic ash (RVF 1998, RVF 2000). If the option exists, the slag can sometimes be utilized as a substitute in selective construction projects for gravel, but the permitting process must still be performed on an individual project basis, which most often deems the process too costly and time-consuming. The other option, of course, is permanent containment of the slag in a properly lined containment system such as a lined landfill. As for the other waste component, the fly ash, must also be contained in a permanent storage system because of the toxic nature of the by-product. It is with this system of waste treatment that a portion of the energy contained in the waste are reintroduced into society, but unlike the bioreactor cell approach, the nutrient chains are kept from being reintroduced because they are mixed with the ash discards, which must be contained in a secure and appropriate manner.
3. Materials and Methods

3.1 Placing Values on Critical Economic Aspects

3.1.1 Bioreactor Cell

There are many aspects of the previously described waste handling systems that can have costs and revenues assigned to them. This can be more easily conceptualized for each treatment through the use of flow charts. In Figure 4, and again in Figure 6, the areas highlighted in Italics show where possible costs and revenues can be attached to each treatment method. Each of these areas represents a domain where either a potential revenue or cost can be recognized by this waste treatment system.

The focus of this study is to compare the values of each of these systems to see which is more cost-effective. Because of the uniqueness of this study, actual data was difficult to

Figure 4: Flowchart for Bioreactor Cell Treatment

The Flowchart for MSW treatment in a bioreactor cell shows where costs and potential (Blue area) revenues occur in the treatment process with a closed system. Costs are incurred for the construction and operation of the facility, while revenues can be recognized in the sale of methane gas and biomass fuel. There is additionally a treatment cost offset if a vegetation filter is used instead of conventional leachate treatment at a WWTF.
locate. The economic values that were obtained have been collected through a number of different channels including scholarly and industry publications, telephone and personal interviews, e-mail correspondence, and other resources. The information pertaining to the construction and operations of the bioreactor cell was obtained through various channels at NSR. Information in the economic calculations for incineration was obtained through specific facility statistics and general numbers for Sweden as a whole. All prices are calculated in Swedish Crowns (SEK). An analysis of treatment in a bioreactor cell will be discussed first.

### 3.1.2 Bioreactor Cell Construction and Operational Costs

There are numerous costs involved in the construction and operation of a landfill bioreactor cell (see Table 1). Furthermore, as can be seen in Figure 5, the major costs can be broken down into three categories; these categories include cell construction costs, methane

<table>
<thead>
<tr>
<th>Table 1: Bioreactor Cell Construction /Operational Costs (MSEK/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bioreactor Liner Costs</td>
</tr>
<tr>
<td>Cell Walls, gas/leachate piping,</td>
</tr>
<tr>
<td>Pretreatment Plant</td>
</tr>
<tr>
<td>Pretreatment Equipment</td>
</tr>
<tr>
<td>Bioreactor Equipment</td>
</tr>
<tr>
<td>Staff</td>
</tr>
<tr>
<td>Infrastructure</td>
</tr>
<tr>
<td>Overhead</td>
</tr>
<tr>
<td><strong>TOTAL Const./Operational Costs</strong></td>
</tr>
</tbody>
</table>

*Source: Lewis-Jonsson 2000.*

**Figure 5: Cost Breakdown for Cell Deposition**

- **Collection System (Leachate & Gas)**: 29%
- **Filling**: 24%
- **Construction Costs**: 47%

The above Figure shows the general breakdown of the three main construction and operation components for a bioreactor cell.

*Source: Lagerqvist 1997.*
and leachate collection system costs, and solid waste filling expenses. The costs obtained form the Filborna represent the significant company expenses for NSR in treating the just over 100,000 tons of waste in 1999. The cell size for this waste quantity would correspond to a 1.2-hectare cell that is approximately 10 meters in depth. The waste density of the cell is 0.85 tons per cubic meter (Meijer 2000).

### 3.1.3 Gas Generation Revenues

A major component of waste treatment in a bioreactor cell is the formation of methane gas (CH₄). The methane percentage generated through the degradation of waste at NSR is 55% (Bengtsson 2000a). It is this methane gas that is the useful portion that is captured by a collection system and transferred to a nearby combination heat and power (CHP) facility located near NSR. For the particular facility, this breakdown is 89% heat production and 11% electricity. The sale of this storable fuel generates a revenue, or income, for the treatment facility. The bioreactor cell at NSR will produce 80,000 MWh of energy per year for the 100,000 of waste deposited in the cell. The price received by NSR for this methane gas from the local energy provider is 130 SEK/MWh (Eken-Södergård 2000). This corresponds to potential revenue of 10,400,000 SEK if all the energy is sold to an energy provider.

### 3.1.4 Leachate Values

As we are aware from the previous section, the landfill facility additionally produces leachates, which are collected year-round in storage ponds near the cell. Leachate generation can be seen both as a cost for the waste treatment operator, and an ultimate income generator through the leachate distribution to an energy

<table>
<thead>
<tr>
<th>Year</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>167,406</td>
</tr>
<tr>
<td>1996</td>
<td>91,953</td>
</tr>
<tr>
<td>1997</td>
<td>70,617</td>
</tr>
<tr>
<td>1998</td>
<td>32,217</td>
</tr>
<tr>
<td>1999</td>
<td>257,134</td>
</tr>
</tbody>
</table>

**Average Leachate Production: 183,856m³**

*Source: Bengtsson (2000b).*
forest as a fertilizer. Table 2 shows the total quantities of leachates generated over the past five years for the complete Filborna area; this is the period since NSR has had a full-scale nutrient recovery system in place. The quantity of leachates produced each year at the Filborna facility is on average 183,856 m³ for each year over the past five years.

There are a few alternatives for management of cell leachates. One manner is treatment through sending the leachates to the local wastewater treatment facility (WWTF), where it is treated in a normal fashion like other household wastewater. For this service, NSR would pay 6.5 SEK for each cubic meter of leachate sent to the facility (Bengtsson 2000b). Treating all of the Filborna facility leachates in this conventional manner would amount to an average annual cost of 1,182,000 SEK each year.

3.1.5 Leachate Purification with Vegetation Filters

The other method of leachate management is through the distribution and purification in a vegetation filter—or an energy crop—grown adjacent to the bioreactor. The advantages of employing this method of leachate treatment is it would most likely be not only more cost-effective than that of that of treatment in a WWTF, but it often leaves the water in a higher level of purity than a normal treatment plant (Börjesson 1999). Furthermore, the utilization of the nutrients contained in the leachates is almost the perfect fertilizer for enhanced growth of an energy crop, such as _Salix_.

As a small side project to this examination, calculations were made using a specialized computer model to determine the size, based on leachate Nitrogen content and quantities, of the required vegetation filter, and the cost (per cubic meter) to treat the leachate from the NSR cell (Rosenqvist 2000). In addition, estimates were made using this model to determine the cost for treating bioreactor cell leachates and the potential net revenue recognized for the sale of the _Salix_ biomass chips to an energy generator.

The benefits of using wastewater in the irrigation of a biomass crop have been examined in Sweden in recent years. Numerous advantages when applying this technique have been discovered including:

- Increased growth rates over both non-fertilized and commercially fertilized crops
- Treatment cost offsets
- Energy savings from commercial fertilizer production
- Decreased eutrophication due to better plant nutrient uptake
- Ideal nutrient and water ratios for crop

Source: Danfors et al. 1998.
3.1.6 Vegetation Filter Calculations

The two critical variables for this calculation is the total quantity of leachates produced, which, as stated is just over 180,000 m³/year on average, and the quantity of Nitrogen in the leachate, which was calculated to be on average 23.8 mg/liter over the past five years (Brander et al. 1999). *Salix* (willow) was used as the crop for this calculation because of conducive growing conditions in this region of Sweden in conjunction with an ample supply data on the crop. Calculations for the vegetation filter included the major cost and revenue components in establishing, growing, harvesting, and distributing the chips to the purchaser (see Table 3).

**Table 3: Basic Assumptions for Vegetation Filter Calculations**

<table>
<thead>
<tr>
<th>Crop</th>
<th>Salix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regrowths</td>
<td>6</td>
</tr>
<tr>
<td>Productive Pd. (yrs.)</td>
<td>22</td>
</tr>
<tr>
<td>Growing Conditions</td>
<td>Sweden</td>
</tr>
<tr>
<td>Price Level (yr)</td>
<td>1999</td>
</tr>
<tr>
<td>Real Interest Rate (%)</td>
<td>6</td>
</tr>
<tr>
<td>Labor Costs (SEK/hr.)</td>
<td>130</td>
</tr>
<tr>
<td>Electricity Costs (SEK/kW)</td>
<td>0.5</td>
</tr>
<tr>
<td>Leachate N-Content (mgN/l)</td>
<td>23.8</td>
</tr>
</tbody>
</table>


These components more specifically include such factors as leachate pump and irrigation system costs, crop establishment and harvest costs, labor costs, weed control, and chip transport costs. On the revenue side, Swedish government crop establishment and EU crop subsidies along with revenues from chip sales were considered. A more detailed description of many of the economic variables used in the vegetation filter calculations along with estimation results can be viewed in Appendix 1.

Leachate holding pond construction and maintenance costs were not considered in the analysis, for the costs are included in the general bioreactor cell costs. Chip prices were calculated form the average price from the latest four years as published by the Swedish National Energy Administration (Enerimyndigheten 2000). From this data the average price was determined to be 114 SEK/MWh. The conversion factor to usable units for our
calculations was 4.5 to convert MWh to ODT (oven dried tons) was then made (Danfors et al. 1998).

Net results from the data collected from the various sources for landfill bioreactor cell treatment can be viewed in Appendix 2 along with where the economic components fall within the waste system.

3.1.7 Post-Closure Care

Because responsibility for the bioreactor cell does not cease precisely when the cell has been filled, the need for post-closure care is required. Estimates in Sweden for these costs have been performed for large- and small-scale facilities. The significant component for the post-closure care of the reactor cell is the addition of the top-cover over the cell area. The cost for this cover has been estimated to be 280 SEK/m² (Carlsson 2000) of cell area. With a cell area of 1.2-hectares (12,000 m²), this quantity becomes 3,360,000 SEK.

The other important components in the area of post-closure care are continued leachate collection, gas collection, and extending monitoring costs. Extended costs for leachate control are estimated to be 4 SEK per ton of waste each year. Additionally, gas extraction costs are also 4 SEK per ton. Cell area monitoring costs are half the gas and leachate costs at 2 SEK per ton (Carlsson 2000).

3.2 Economic Valuation for MSW Incineration

Calculations were also made for solid waste incineration in Sweden. Where the analysis for incineration differs from that of bioreactor cells is from how and where the data was obtained. As mentioned, because of the lack of site-specific data available for this investigation, general numbers for the construction and operation of an incineration facility were obtained from different facets of the waste industry in Sweden.
Figure 6 (in Italics) displays where variables can be attached to the important economic components for MSW incineration. Representing a typical facility that would be constructed also in southern Sweden, calculations were made on the basis of a newly constructed facility that meets current European Union standards, incinerates 25 tons of waste per hour, and operates 8,200 hours per year (Sysav 2000). With this operating time, this would correspond to just over 200,000 tons of waste incinerated each year. The life of the facility was estimated to be 20-years (Eek 2000). The meaningful variables considered for waste incineration were facility construction and operational costs, system by-product treatment costs, and revenues received for the sale of heat and electricity (see Table 4). Energy production efficiency rates were calculated from the 1999 values as received from the Swedish Association of Waste Management (RVF). Energy recovery from waste incineration facilities has been progressively increasing in efficiency to a point where a waste incinerator can now generate on average three megawatt-hours for every ton of waste handled (RVF 2000, Sysav 2000). The price received for the sale of the energy to the energy supplier is 100 SEK/MWh (Eek 2000)—slightly less than that of the storable energy from the bioreator cell. The values of these relevant categories can be seen in detail in Table 4.

*Figure 6: Flowchart for MSW Incineration*

The flowchart above describes MSW treatment through incineration. There are both costs and revenues (Blue) that can also be placed in the appropriate areas of the system.
An important aspect of the incineration of household waste is the product, namely, the slag and ash, which remain after the process. Because they must usually be dealt with in a careful manner, disposal costs for these by-products are significant. Incineration slag disposal fees are estimated to be 500 SEK/ton, while the smaller portion, the incineration ash disposal costs are 800 SEK/ton (Eek 2000).

A summation can be seen in Appendix 3 for the economic variables used in the calculations for incineration along with where they fall within the incineration flowchart.

4. Results

4.1 Economy of Bioreactor Cells

4.1.1 Costs in Bioreactor Cell Treatment

Using the data collected from the various sources, calculations were made to determine the approximate costs per ton of waste for each solid waste treatment method. As mentioned for handling in the bioreactor cell, the significant costs and revenues obtained from NSR were used to determine the net solid waste treatment cost. The costs to construct and operate a bioreactor cell were calculated to be just over 15.5 million SEK each year. This cost corresponds to 145 SEK/ton of solid waste treated if divided by the 107,000 tons of waste the bioreactor cell accepted in 1999.
Another consequential aspect to the cost of bioreactor is the cost associated with treating cell leachate. Leachate treatment costs fluctuate rather greatly each year due to the quantity of leachate generated. Over the past half-decade this average leachate quantity has been 183,856 m³, which becomes an average 1,195,764 SEK/year expense when multiplying this by NSR's 6.5 SEK/m³ treatment cost. Adding this factor into the treatment cost for the bioreactor cell the cost becomes 16,745,764 SEK/year or adding 11 SEK/ton of waste treated. Adding this quantity to NSR's general construction and operating expenses a cost of 156 SEK/ton of waste is obtained. Leachate treatment—and overall bioreactor cell—costs can be further reduced if leachate treatment using a vegetation filter is utilized. The cost of leachate treatment is reduced to 21,972 SEK/year when the 20-hectare *Salix* vegetation is used to treat the average quantity of bioreactor cell leachate. This expense adds only 0.2 SEK onto the price per ton of waste treated. The savings of over one million SEK become a major aspect in cutting system operation costs over both the short- and long-term periods. With the implementation of a vegetation filter, the annual costs for the treatment of waste is 15,521,972 SEK/year, or slightly over 145 SEK/ton of solid waste. Because of rather significant yearly leachate generation fluctuations, it was also deemed important to show the cost of treating leachate at differing levels of Nitrogen concentrations and leachate quantities. Table 5 shows the cost

### Table 5: Vegetation Filter Treatment Costs Based on Vegetation Filter Size

<table>
<thead>
<tr>
<th>Veg. Filter Size (ha)</th>
<th>Treatment Cost (SEK/kg N treated)</th>
<th>Treatment Cost (SEK/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>50</td>
<td>0.90</td>
</tr>
<tr>
<td>20</td>
<td>36</td>
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<tr>
<td>30</td>
<td>56</td>
<td>0.56</td>
</tr>
</tbody>
</table>

Calculations for leachate treatment costs using a 10, 20, or 30 hectare *Salix* vegetation filter. Treatment costs were determined for both kilogram of Nitrogen treated and costs per cubic meter of landfill leachate.

*Source: Rosenqvist 2000.*
4.1.2 Post-Closure Costs
An additional cost to the bioreactor cell operator is the costs associated with maintenance and monitoring of the cell area after it has been filled. The most significant costs pertain to the addition of the top cover to the cell area. This cost augments the treatment expenses by 32 SEK/ton of waste handled.

In addition to the top-cover expenses, cell gas, leachate, and monitoring costs add 10 SEK/ton of waste to the post-closure costs. The combination of these four areas brings costs to the cell operator to 42 SEK/ton of waste treated.

4.2 Bioreactor Cell Revenue Sources
4.2.1 Vegetation Filter Revenues
The use of a vegetation filter to treat landfill bioreactor cell leachate also has the potential to become a small revenue source for the bioreactor cell operator through the cultivation and sale of the biomass to an energy provider as a sustainable fuel source. As mentioned, a 20-hectare vegetation filter was used, which would effectively treat the average quantity of leachate produced by the bioreactor cell each year without causing excess chemical runoff.
From this space, an average net revenue of 83,480 SEK/year would be recognized for the sale of the *Salix* chips. This quantity becomes an approximate 0.75 SEK/ton of waste cost offset when determining the price per ton of waste treated by this method.

### 4.2.2 Methane Gas Revenues

Another revenue that can be recognized in the treatment of solid waste in a bioreactor cell is the potential for payments from the energy sector for the methane gas generated in the decomposition of the waste in the bioreactor cell. As calculated, payment for the gas generated in the cell could counter-balance system costs by 10,400,000 SEK/year. If all the energy is sold to a power generator, this option reduces the net treatment of waste by 97 SEK/ton.

### 4.2.3 Net Treatment Costs for Bioreactor Cell Treatment

Combining all the numbers for MSW treatment in a bioreactor cell, two sets of figures are reached. The first corresponds to treatment without the use of a vegetation filter. This net treatment cost then becomes 101 SEK/ton of waste. If a vegetation filter is used in this handling system, a further cost savings is recognized. This number is reduced to 89 SEK/ton of waste. The treatment savings are a result of both the reductions in leachate treatment at the wastewater treatment facility and the small revenue that is recognized with the sale of the biomass fuel.

### 4.3 Economy of Incineration

#### 4.3.1 Costs for Waste Incineration

Evaluation of the cost of solid waste incineration can be performed in much the same manner as that of treatment in bioreactor cell treatment. As seen previously in Table 4, the costs for constructing, maintaining and operating an incineration plant in Sweden are significantly greater than that of a bioreactor cell. Adding the relevant costs, we can see that a newly constructed facility that treats 25 tons of waste each hour and operates on average 8,200 hours per year will have construction and operational costs of 495 SEK/ton of waste treated.
4.3.2 Ash and Slag Disposal Costs
In addition to facility costs, there also exists the costs for disposal of the roughly 25% slag and ash by-products that remain after the process is completed. As shown previously in Table 4, slag disposal costs are 500 SEK/ton and disposal of toxic incineration ash is 800 SEK/ton. This process by-product adds 140 SEK/ton to the treatment cost per ton of waste. Combining these two figures, one sees that the overall costs for a facility will be approximately 635 SEK/ton of waste treated by incineration.

4.3.3 Energy Generation Revenues
Because of the large cost, incineration facilities must employ methods, such as energy recovery, to gain some of the treatment expenses back. This recovery corresponds to a rather significant 615,918 MWh energy each year for the facility handling the 25 tons of waste/hour. Combining this energy quantity with the average payment amount of 100 SEK/MWh of energy in Sweden, this becomes an important cost offset for facility operations—a 61,591,800 SEK revenue addition. This value translates to 300 SEK/ton of MSW calculated back in revenues to the operation of this waste management method.

4.3.4 Net Treatment Costs for MSW Incineration
Like solid waste handling in a bioreactor cell, it is additionally possible to obtain a cost per ton of waste for incineration. Combining both the costs to construct and operate the facility with the revenues from the sale of the heat and/or electricity to the local energy supplier, the net cost for this waste treatment method becomes 335 SEK/ton of waste—significantly greater than that of treatment in the bioreactor cell.

5. Discussion
5.1 Examination Results
Because the present economic system still allows for the sub-optimal utilization of resources, it is of the utmost importance to employ waste treatment systems that not only close as many of nature’s cyclical loops as possible, but it is also critical to do it in a manner that is not excessively cost-prohibitive to society. The hypothesis of this study postulated that there is a method of solid waste management that is not only environmentally more sustainable, but
was also a much more cost-effective way to treat waste. From the results received, this hypothesis was proven. It has shown that MSW treatment in a bioreactor cell is the technique that can be employed for roughly 90 to 100 SEK/ton of waste, while MSW incineration costs are over 300 SEK/ton. We have seen that the landfill bioreactor cell method of waste handling is approximately three-times cheaper to employ, while at the same time, having the possibility of utilizing both nutrient and energy chains for effective reintroduction back into human society for use.

With this study, it can moreover be seen that landfill bioreactor cell approach also carries with it the potential to treat cell leachates in a more sustainable and cost-effective manner through the establishment of an energy crop or vegetation filter of some sort. The implementation of such an agricultural mechanism is strongly supported, not only for ecological reasons, but also for the cost savings that are achieved by not purifying the leachate at a WWTF. This savings, from 11 SEK/ton of waste down to 0.2 SEK/ton, is a factor that can save a bioreactor cell operator's, such as NSR, significant expenses each year. It is also recognized that the additional income generated through the sale of the biomass fuel source does not influence the cost of treating waste by this method greatly—reducing costs by less than one SEK/ton.

5.2 Bioreactor Cell Discussion Points

5.2.1 Space Consumption

Beyond the analysis results, there are a number of significant factors that must be discussed in the examination of these two handling systems. One of the most important aspects focuses
on the bioreactor cell vegetation filter. The use of such a system is not only a significantly more economical way of treating bioreactor cell leachates, but it is also essential for the reintroduction of a critical component back into the ecological cycle (Bramryd 1997-98). This component, of course, is the bioreactor cell leachate nutrients. Today, globally, only a small number bioreactor cells make use of leachate nutrients through the use in such things as bioenergy crop cultivation; instead the vast majority simply either recirculate leachates back through the bioreactor cell, or send system leachates directly to the wastewater treatment facility for conventional purification.

Establishment of this more natural and cyclical purification system presents a number of both ecological and economic possibilities, but at the same time also presents some restrictions. Creation of a vegetation filter adjacent to a bioreactor cell could present possible space constraints. As calculated in this analysis, the space required for safely treating the average amount of leachate at a facility treating just over 100,000 tons of MSW per year is determined to be 20 hectares. Not every bioreactor cell location may have this amount, or more, of space available for the establishment of a vegetation filter next to the reactor cell, especially larger-scale treatment sites that treat in excess of 200,000 tons/year.

If land is available for the establishment of a vegetation filter, cost can become an additional prohibitive factor. Acquiring additional land not only increases the cost of overall bioreactor cell treatment, but also can attach with it elevated costs to the vegetation filter irrigation system, thus increasing overall leachate purification costs while diminishing net income from the energy crop.

5.2.2 Bioenergy Infrastructural Development

Another factor that is critical for the functioning of this purification system is the state of the energy system near the facility; biofuel infrastructural components also must be established for this system to function effectively. Utilization of such a system assumes that a proper system exists for the processing and generation of energy from biomass fuel. With an economy based strongly on the forestry industry, Sweden presently has such a well-established wood chip market based on forest residue products, but this is not true for many countries. Adding to these benefits there are also numerous generation facilities located around the country that can burn this biofuel product creating both a demand for this fuel source along with a more stable price system.
5.2.3 Interchangeable Vegetation Filters

For this comparison the energy crop *Salix* was used in the calculations to determine, not only the vegetation filter size for leachate purification, but also the potential revenues from the sale of the biomass chips. As noted, Sweden’s rather extensive experience with *Salix* coupled with a reliable supply of information on such things as growth rates to chip prices, made the use of this crop the a worthy choice for these calculations. But it is also acknowledged that other crops can be substituted instead of *Salix* with quite similar results (Bramryd 2000, Rosenqvist 2000). Varieties such as popular, birch, or energy grasses, can also be cultivated for biofuel purposes instead of willow. Soil and climatic conditions will play a key role in determining which crop would be suitable for which areas. With the switch of crops one could expect differences in growth rates, yields, harvest costs, but the results would ultimately prove to be insignificant in the overall calculation of bioreactor cell costs and revenues.

5.2.4 Biomass Ash

Both the CLD and the flowchart for solid waste treatment in a bioreactor cell showed components for reintroduction of biomass ash back into the system. Even though this is a critical aspect for the reintroduction of a component for this waste treatment system, the economic factors were left out of the calculations for this study because they are not borne directly on the reactor cell operator, but instead, the energy producer. The biomass ash by-product under normal circumstances becomes an expense for the energy generator because there is a disposal cost that must be paid when discarding the ash. But, because of the clean nature of this ash, it also has the potential to become a revenue source for the energy generator if it can be sold back to the forestry system as a fertilizer or soil stabilizer against soil acidification, which is a on-going problem in Scandinavian countries.

Although larger-scale formal networks have not been established between energy generator and the forest industry yet, smaller, individual ash exchanges between individual energy generators and local forest growers are progressively being established throughout Sweden (Jander 2000).

With the introduction of the Swedish landfill tax, there has been added incentive for energy generators to find alternative means to dispose of biomass ash. This tax now provides an
additional cost for ash disposal, which ultimately has a negative effect on energy generation costs. Because of these heightened financial pressures, along with increased efforts by Swedish energy generators to increase their environmental consciousness, we will see increased developments in this arena in coming years.

5.2.5 Leachate Fluctuations
An area of uncertainty for the operation of a bioreactor cell is the yearly fluctuations in cell leachate production. As can be seen in Table 2, large fluctuations in leachate occur even in well-established bioreactor cells such as the Filborna site. Over the past five years this quantity has been as little as 32,000 m$^3$/year up to in excess of 257,000 m$^3$/year of leachate. This fluctuation becomes important when leachate must be stored in holding ponds near the bioreactor cell before distribution to a vegetation filter—meaning that the quantity of leachate generated can't exceed the capacity of the storage pond. If this were to occur, bioreactor cell leachate would then be required to be sent directly to a treatment facility, or be immediately re-circulated back through the bioreactor cell to avoid an overflow. To avoid this, it means that the holding pond must be large enough to support the quantities of leachate produced in high generation years. This factor places extra economic constraints on the reactor cell operator, for construction costs for leachate holding pond, or holding pond expansion are significant.

Another important factor to discuss when examining solid waste treatment in a bioreactor cell is leachate quality issues. The use of a vegetation filter for leachate treatment is only effective when chemical concentrations are at a level that the biomass crop can effectively handle. If compound levels, such as salts, in landfill leachates is not optimal, growth problems can occur in the crop, thus reducing the effectiveness of the vegetation filter and ultimately reducing biomass revenues.

5.2.6 Leachate Recirculation
From the results in this study, one can see that not only are there potential ecological and economic benefits from utilizing treatment of municipal solid wastes in a bioreactor cell, but the employment of a vegetation filter for leachate purification is additionally an added bonus to this treatment system. As mentioned, many landfill bioreactor cells today use recirculation to deal with system leachates. This technique provides the liquids needed to increase the
microbial breakdown of the waste within the cells while saving the rather significant leachate treatment costs at a WWTF (Pacey et al. 2000). But recirculation is by no means a perfect solution. First, with leachate recirculation, the nutrients contained in the cell are lost from reintroduction back into society—thus making it a less sustainable MSW management system. Additionally, recirculation also has some technical problems that must not be overlooked. Tom Kraemer, an engineer in the United States argues, “The principle is great, but the mechanics of recirculating leachate are difficult. Unless you’re very careful about how the leachate is reintroduced, it may concentrate in localized areas of the landfill” (Hull 2000). This concentrating of leachate causes rapid decomposition in some areas of the cell, while only gradual decomposition in other areas, leading to differing settlement patterns throughout the bioreactor (Hull 2000). It is because of these differing settlement patterns that large potential problems such as liner breakage or cell wall collapse within the containment area could occur from the increased pressures from the added liquids.

5.2.7 Post-Closure Cell Monitoring

Another component that was considered in this investigation was economic value placed on monitoring and care of the landfill bioreactor site after final closure of the cell. Although these costs ultimately impact the price of waste treated by this method, especially the addition of the top-cover, it is not the major cost to this method of handling. It is also important to note, as argued by Pacey et al. (1999), Sullivan (2000), Lee & Jones-Lee (2000), the bioreactor cell approach to waste treatment would actually reduce post-bioreactor cell costs over conventional waste treatment methods through the increased waste stabilization and gas extraction. The stabilization of wastes has been estimated to be within five to ten years (Pacey et al. 2000), and the “LFG (Landfill Gas) generation (and subsequent recovery) is anticipated to be a 10- to 15-year life after landfill closure, thereby significantly limiting the post-closure period for landfill control” (Sullivan 2000). This becomes an important factor in alleviating long-term monitoring costs over that of conventional landfillsing where attempts to stabilize waste, but merely contain it in an enclosed space are not made.
5.3 Incineration Discussion Points

5.3.1 Incineration Economies of Scale

When examining waste treatment by incineration, economy of scale becomes an important issue. To be cost-effective, the quantity of solid waste that must be treated in a newly constructed facility must be large. Today, these plants can handle in excess of 200,000 tons each year—operating up to 24-hours each day. It is also possible that this aspect presents possible conflicts in waste reduction policies and discouraging waste generation because of the reliance on these quantities of waste to keep the facility operating at desirable levels. This demand can additionally have detrimental effects on local waste policies that encourage separation and minimization of wastes, thus, adversely impacting material take-back rates.

5.3.2 Facility Locale

It is acknowledged that the land requirements for treatment in a bioreactor would utilize more space, with or without the use of a vegetation filter, than that of an incinerator. But with this said, actual facility placement also becomes important. Compared with placement of landfill bioreactor cells, incineration facilities are often placed in a more centrally located, urban area. This is important from the perspective that land prices would most likely be significantly greater in an urban area than that of a more rurally located landfill bioreactor cell facility (Bramryd 2000). But there is an additional factor that also is important when discussing facility location.

5.3.3 Transfer of Waste for Incineration

If solid waste quantities are not available from a close proximity to the incineration facility, waste must then be trucked in from greater distances to keep the facility operating at an effective level. This demand impacts the environment adversely through the creation of increased traffic and augmented exhaust emission levels from solid waste transport vehicles. These increased traffic levels are also created where urban infrastructures need it the least. Incineration facilities are most commonly constructed close to urban areas to reduce overall transportation requirements. But it is in these same areas that more highly congested roadways already exist, thus creating larger traffic problems. This is in direct contrast to the location of bioreactor cells that are often located outside the city limits further, thus reducing congestion problems.
5.3.4 Swedish Policy Instruments

The 250 SEK/ton of waste landfill tax that was implemented in January 2000 will have strong impacts on the direction Swedish waste treatment methods progress in the near future. Because MSW deposited in landfill bioreactor cells are currently subject to this tax, it presently places them slightly at a financial disadvantage. The tax situation on municipal solid wastes in Sweden is by no means stable though. But with a growing resistance to MSW treatment through incineration, there has been talk recently in governmental arms not to abolish the present landfill tax, but to similarly implement some sort of economic mechanism to curb the rather fast paced development of incineration. This mechanism would most likely also be in the form of taxes on incinerated waste—creating an additional cost to this already expensive treatment method.

6. Conclusions

When examining solutions for minimizing the impacts of today’s solid waste chains, it is essential to investigate how the numerous systems interact to create the present situation. As we have seen, the political system in Sweden is the fundamental driver of, through economic-based policy instruments, waste treatment techniques based now significantly on the burning of waste. But with this movement, it is imperative that we periodically step back and examine if these choices are both environmentally and economically optimal. This study has demonstrated that the current path that countries such as Sweden are following in MSW treatment may not be the most optimal path for both more sustainable and cost-effective waste treatment systems. The major findings of this study have established that:

- MSW treatment in a landfill bioreactor cell is not only theoretically a more sustainable waste treatment system than MSW incineration, but it is also a much more economical system
- Even when national landfill taxes in Sweden are applied to household waste being treated in a bioreactor cell, the treatment costs are still roughly equivalent to that of incineration
- Different options are available for leachate treatment in landfill bioreactor cells, but treatment utilizing vegetation filters is not only the best option ecologically, but also carries with it the lowest economic costs
Closinf Waste Loops: An Economic Comparison of MSW Treatment Systems in Sweden

- The most significant factor in the utilization of a vegetation filter for leachate purification is not the net revenues received from the sale of the biomass chips, but the cost aversion of sending the leachate for purification at a municipal wastewater treatment facility.
- Because of the present lack of information and analysis available on this subject, further research should be conducted in this important multi-faceted area.
ClosinJ! Waste Loops: An Economic Comoarison of MSW Treatment Svstems in Sweden

References:


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Eek, J. (2000) (Sysav Company) Information on general treatment costs for incineration provided via e-mail. 13 September.


Closing Waste Loops: An Economic Comparison of MSW Treatment Systems in Sweden


Appendix 1: Variables & Results Used in Vegetation Filter Calculations

<table>
<thead>
<tr>
<th>Crop</th>
<th>Salix</th>
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<tbody>
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<td>Productive Pd.</td>
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**Results:**

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<tr>
<td>With Gov't Subsidies</td>
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</tr>
<tr>
<td>Income</td>
<td>.77 SEK/ton waste</td>
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The above figures represent the variables used in the calculations for determining the size of the vegetation filter required to effectively treat the bioreactor cell leachates, the costs to treat the leachate, and the recognized revenue from the sale of the biomass fuel.

*Source: Brander et al. 1999, Rosenqvist 2000.*
Appendix 2: Bioreactor Cell Flowchart with Attached Economic Variables (SEK/ton)

The above Flowchart shows where costs and revenues have been attached in the various parts of the treatment process. Also note that the areas denoted in green are important aspects in obtaining a closed loop system for this process, but were not considered for the study.
Appendix 3: Incineration Flowchart with Key Economic Variables Attached (SEK/ton)

The areas in color represent the significant economic variables for MSW incineration as they fall within the material flow of the system.