On-site Composting of Restaurant Organic Waste: Economic, Ecological, and Social Costs and Benefits

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Abstract On-site composting is examined as an alternative method of organic waste disposal in San Francisco Bay Area restaurants. Since 74% of an average restaurant's waste stream is compostable material, composting and reuse of organic material would redirect a significant portion of the waste stream from landfills. Economic, ecological, and social costs and benefits of three methods of organic waste disposal are compared: landfilling, off-site composting, and on-site composting. A waste characterization of one large Emeryville restaurant is performed to determine the mass of the organic waste generated. An economic analysis of the three methods of organic waste disposal is made for the specifications of this particular restaurant and ecological and social considerations are proposed for each method. Two commercially available composting technologies are compared. For the more appropriate technology, present discounted value and payback period of the hypothetical investment are calculated based on the current expenditures for landfilling service. An ecosystem modeling method is performed as a means to visually represent ecological sustainability. A life-cycle approach is taken to determine the ecological impacts of the use of agricultural soil conditioners and fertilizers, impacts that would be curbed to the extent that restaurant compost is used in their place. Social costs and benefits are compared based on the goal of economic, ecological, and social sustainability as a follow-up to the scientific results. It is found that on-site composting is ecologically, socially, and economically more valuable than landfilling or off-site composting, although significant management constraints exist at this point in time when a composting infrastructure is not yet in place. It is also found that a significant market exists for a middleman firm that would incur the management responsibilities of on-site composting and benefit from the sale of restaurant compost. It is recommended that local governments exploit this market.

Introduction

Currently, the US commercial sector generates 24.6 million tons of food scraps and soiled, unrecyclable paper and cardboard annually (United States Environmental Protection Agency [EPA] 1999). In restaurants, organic materials make up an average of 74 percent of the total waste stream (EPA 1999). Composting redirects organic waste from landfills and transforms the waste into a product useful in landscaping, gardening, maintaining the structure and fertility of agricultural land, slope stabilization, and even brownfield remediation. The increasing sophistication of the available composting technology combined with the passage of AB 939, which mandates a 50% waste stream reduction goal for the state of California by the year 2000, have exposed widely used landfilling as a disposal method wasteful of both space and a potential resource. An anticipated rise in landfilling fees may lead businesses to seek alternative methods of food waste disposal. These combined factors have created an impetus for research on the relative economic, ecological, and social costs and revenues of organic waste composting in the Bay Area.

Composting is a biological process in which microbes metabolize readily degradable organic matter into nutrient rich humus, a structural component of soil.[1] Specific criteria must be met for composting to be successful, and meeting these criteria is especially important for large-scale industrial composting operations. Technology is currently available to allow low-maintenance pest and odor controlled on-site composting of organic residuals at restaurants. Organic residuals are plant and animal derived and include pre-consumer vegetable scraps, seeds, all animal product including bones, post consumer food waste, paper products, including waxed cardboard, and wood, including treated wood (Brandt, 1996). The addition of compost to agricultural land and urban landscaping areas provides many associated ecological benefits including reduced dependence on chemical fertilizers and reduced pollution by accumulation in landfills. Composted food waste is currently classified by the EPA as Class A material, rendering its land application unregulated (Miller and Miller 2000).

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[1] Microbial populations and species diversity change dramatically throughout the phases of the composting process. Initially, mesophilic bacterial and fungal activity cause the temperature of the organic matter to rise into the thermophilic range, >50°C. Thermophilic microbes, especially actinomycetes, maintain thermophilic conditions within the organic matter if provided with sufficient oxygen. This requirement is met through aeration of the organic material. Mesophylic microbes are present during the final curing stage at lower temperatures. The heat generated during the thermophilic phase of composting is intense enough to kill pathogens and seeds (EPA 1998).

Food waste has been used as a soil amenity as far back as the middle ages in Europe, and evidence in Amazonia suggests that food processing wastes were added to soils around the same time (Miller and Miller 2000). By 1940, inexpensive inorganic fertilizers had become widely available and used due to their short-term results on crop yields; but more recent evidence of adverse ecological effects such as contamination of water supplies due to inorganic fertilizer application has led to a renewed interest in organic fertilizers.

Various methods of organic residuals management should therefore be evaluated based on three categories: economic value, ecological value, and social value. Revealing categorized benefits and deficits of various methods allows for an in-depth, multilayered comparison of those methods. Economic costs and revenues are equal to the current actual costs and revenues of managing organic residuals in various existing or hypothetical ways. Ecological costs and revenues can be determined through the valuation of environmental externalities with regards to energy consumption, materials cycling and pollution generated and avoided. Social costs and revenues can be determined through an analysis of the long- and short-term value inherent in initiating re-use behaviors vs. the maintenance of waste behaviors.

Study Focus It is hypothesized that on-site composting is more ecologically and socially valuable and less economically valuable than landfilling organic waste in the San Francisco Bay Area. This study attempts to identify, compare and contrast the economic, ecological, and social values of three methods of food residuals management by the food service industry in relation to high-volume Bay Area restaurants. The first of three methods of food residuals management is landfilling, or the disposing of "waste" in specifically Bay Area containment facilities. The second method is city or county contracted commercial composting where responsibility for composting is assumed by a government body. On-site commercial composting is the third method: responsibility for composting and the resultant composted product is assumed privately by the individual restaurant.

Materials and Methods

Study Sites Specifically targeted is Chevy's of Emeryville, CA whose current method of waste disposal is landfilling. The cost of its current method of organics residuals disposal will be compared with two alternate methods of disposal/reuse. Park Chow Restaurant will be studied as a reference for current costs to restaurants for a Bay Area city contracted organics composting program. Park Chow of San Francisco whose current method of waste disposal is composting of organics, recycling of recyclables, and landfilling of a minimum of materials pays a city contracted composting company to compost and recycle its pre-sorted waste.

Waste Characterization In order to identify the organic waste component of Chevy's waste stream, a waste characterization study was conducted. Average waste density was determined, and total waste volume generated per week was roughly determined. The quantity of organic waste generated per day was calculated using an EPA-determined percent organic waste by mass of an average restaurant's waste stream.

In order to determine the average density of the waste stream, each bag of trash was weighed upon being put into a single empty $3yd^3$ dumpster using a common bathroom scale. The dumpster was allowed to fill to the halfway mark, $1.15m^3$($1.5yd^3$) during the course of the day. Because the large volume of waste measured is a representative sample (trash bags were weighed from the opening of the restaurant until closing time) only one trial was made.

Total waste volume data was taken over a week. Trash collection is four times weekly, and total waste volume was measured just before collection on each of the four collection days. Total waste volume generated per week was roughly determined.

A rough determination of total waste volume generated was made due to the time and labor involved in a more accurate determination. An order of magnitude determination is of fundamental importance, but a very accurate determination is labor intensive. Due to the nature of the food service industry, business (and thus waste created) can fluctuate weekly, seasonally and annually. Furthermore, percentage of organics in waste streams varies among Bay Area restaurants, and although Chevy's will be analyzed more specifically, it is also useful to provide a flexible model that can be applied to many Bay Area restaurants. Possible ranges of these values are given.

It was important to this study to identify the compost machine capacity appropriate to the restaurant, and not necessarily a highly accurate waste characterization. Statistical significance tests were not appropriate to the type of data collected.

Economic Analysis The cost of Chevy's current method of landfilling will be compared with a theoretical model in which the restaurant adopts on-site composting. In the case that on-site composting proves to be a larger economic investment than landfilling, as hypothesized, circumstances that might make composting economically feasible, such as sale of the compost product, will be examined. In the case that on-site composting proves to be a lesser economic investment than landfilling, present discounted value and payback period of the initial capital investment will be calculated.

Two commercially available composters will be compared in a theoretical scenario where Chevy's would replace landfilling with composting and recycling. Green Mountain Technologies' Earth Tubs™ and Wright Environmental Management, Inc.'s small in-vessel automated composter are the two products under scrutiny. Data for each product were obtained through series of personal communications with representatives from each company. The writer endorses neither product.

Life Cycle Approach "Lifecycle assessment (LCA) is used to measure the environmental inputs and outputs associated with a single product or service from the mining of raw materials, through production, distribution, use and re-use or recycling, to final disposal. This is carried out in terms of raw materials, energy use, emissions to air and water and solid waste" (Powel, et al 1998). It "is a technique for assessing the environmental aspects and potential impacts associated with a product, by:

- compiling an inventory of relevant inputs and outputs of a product system;
- evaluating the potential environmental impacts associated with those inputs and outputs;
- interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study." (Frankl and Rubik 2000)

Finally, LCA consists of economic valuation of environmental impacts which assigns a dollar value to these impacts to effectively compare them to real market values. As the economic valuation process requires personnel and funding unavailable to this research, a full lifecycle analysis of the food service industry is beyond the scope of this paper. A limited "lifecycle approach" [4], which can be considered to consist of all components of LCA save economic valuation, will be conducted to provide a complete qualitative analysis of the ecological impacts created or curbed by the three aforementioned methods of organics residuals management.

Ecosystem Modeling It is argued that modeling human industrial processes after natural ecosystems is necessitated both by an increasing human population in a finite material world and by the fact that decisions made on the basis of short-term criteria can produce disastrous long-term results on a global scale. Comparing industry to ecosystems with regards to materials and energy, then, allows an analysis of the degree of deviation of human activity from an ecologically sustainable biosphere (Graedel and Allenby 1995). Various organic restaurant waste management systems are represented visually and compared with regards to ecological sustainability.

Social Costs and Revenues Social ramifications of the three methods of organics management are compared as trade-offs, although various social costs are in no way meant to be interpreted as equivalent to one another. Whether social ramifications are labeled as “costs” or “revenues” is highly subjective, but the labels are grounded in the writer’s concept of sustainability, and where ecological, economic, and social sustainability are perceived as goals.

Results

Waste Characterization The average density of Chevy’s waste stream was determined to be 207kg/m^3 (7322lbs/21yd^3). The total waste volume generated was determined to be approximately 2.3m^3/day (21yd^3/wk). The EPA (1999) has determined that on average, the organic component of a restaurant’s waste stream is 74% by mass. Thus the mass of organic waste generated is

$$207 \text{ kg/m}^3 * 0.74 * 2.3 \text{ m}^3\text{/day} = 352.3 \text{ kg/day}$$

This value is probably a slight overestimate: the total waste volume generated was determined by counting the number of filled dumpsters per week from which bottles and cans were not separated out. If this restaurant were to adopt on-site composting, which inherently involves source separation of waste, bottles and cans would be recycled rather than landfilled. Approximately 50 cases of glass bottles are ordered, and thus thrown away, per week. This amount of recyclable material occupies approximately 1m^3 per week.

Wright Environmental Management, Inc. (WEMI) makes two small-scale in-vessel composting units: a 273 kg/day (600lb/day) unit and a 455kg/day (1000lb/day) unit. Each unit can accommodate 66% of this mass in restaurant waste; the remaining mass comes from the added bulking agent. The larger of the two units, which can accommodate 300kg of organic restaurant waste per day is the appropriate size for a hypothetical Chevy’s on-site composting operation. This unit lists at $67 500.

Economic Analysis

Site: Chevy’s, Emeryville, CA

Three scenarios of organic residuals management are analyzed and compared with regards to economic value only. Ecological and social considerations for each scenario are proposed.

Scenario 1: All waste landfilled except cardboard

The restaurant will operate as it does currently without separation of organics, and with all materials save cardboard being hauled and landfilled. Waste containers are owned by the hauling and landfilling company. Three 3 cubic yard containers are hauled four times weekly. The cost per year for pickup and landfilling is $ 23 052.

Ecological considerations for Scenario 1: Lined and monitored landfills in the Bay Area present few immediate environmental impacts, but the fact remains that landfilling is an inherently nonsustainable practice. Disposing of waste materials in landfills renders materials impossible to separate and reuse due to the high degree of mixing and the presence of toxic contaminants. Furthermore, landfilling of materials is an immediate waste of potential resources and contributes to the unnecessary mining of raw materials and production of secondary materials which in turn creates pollution and disrupts the normal functioning of ecosystems. The anaerobic decomposition which food undergoes in an oxygen-poor landfill environment produces methane, a greenhouse gas.

Social considerations for Scenario 1: “Waste” must be perceived as a natural resource for the maintenance of a sustainable society. Assuming that sustainability is a goal for human society, continuing to rely on the practice of landfilling for materials as readily degradable and reusable as food residuals serves to retard the attainment of this goal.

Scenario 2: Off-site composting

The cost of off-site city-wide commercial composting for a single restaurant is estimated to be approximately equivalent to the cost of landfilling for that restaurant. This result is extrapolated from the approximate equivalence in cost between landfilling and off-site composting incurred by Park Chow restaurant which recently underwent this switch (Hanek 2001, pers. comm.). Due to the high number of employees and the large amount of transportation necessary for such a composting program, this preliminary estimate is reasonable.

Ecological considerations for Scenario 2: The transportation of organic residuals, which is a necessary intermediary between restaurant and composting facility, can tax the environment. Organic residuals are heavy, as they are composed of approximately 70% water. Currently, diesel trucks transport food residuals and compost in off-site composting programs. Figure 1 shows how total transportation can be significantly farther in an off-site composting scenario than an on-site composting scenario. Diesel trucks consume nonrenewable energy and contribute to non-point source pollution.

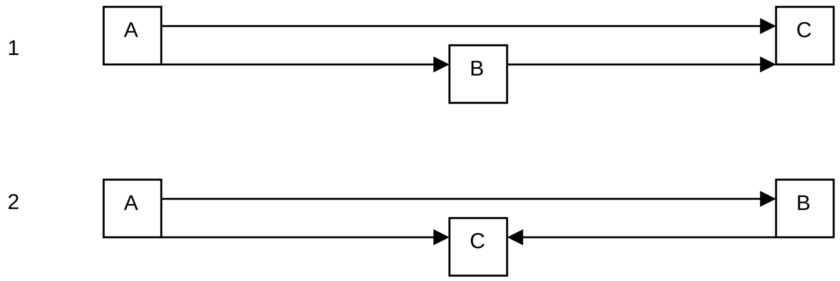

Figure 1 A represents the restaurant, B represents the off-site composting facility, and C represents the site of compost use. The arrows represent distances traveled for different spatial arrangements. In case 1, distances traveled for off-site and on-site composting are equivalent. In case 2, the distance traveled for off-site composting is much farther than that for on-site.

Scenario 3: On-site composting of all organics, recycling of cans, bottles, cardboard

Organics will be separated from the rest of the waste stream at no extra cost. Chevy's employees will carry out sorting as a new job routine. As sorting will be carried out, bottles and cans will be recycled at a minimal cost. Cardboard is currently recycled free of charge.

In the design of a composting system for a high volume restaurant, several considerations must be made. First, organic waste must be stored for a minimum time period to maintain a pest-free restaurant. Each Green Mountain Technologies' Earth Tubs™ require a fourteen-day period of mixing without loading (Bernard 2000, pers. comm.). A single-tub system would therefore require a fourteen-day organic waste storage time. Multiple-tub systems could reduce this storage time, but the space and labor required for such a system deem the system inappropriate to the scale of Chevy's waste stream, and space and labor availability. The benefit of the Wright Environmental Management, Inc. in-vessel unit is that it has a continuous loading capability, such that organic waste storage is avoided altogether. The Wright unit is also extremely low in labor intensity compared with the Earth Tubs™ system. The Wright Environmental Management, Inc. system is evaluated here.

Second, a bulking agent is required for all aerobic composting of food residuals. Two choices are available: shredded cardboard and wood chips. Corrugated cardboard is a waste product in every restaurant. Restaurants generally generate high quantities of this waste material. Recycling cardboard is efficient and widely practiced. Furthermore, local collectors benefit from the free supply of cardboard which they transport to the recycling facility and for which they are paid. However, cardboard is an effective bulking agent, and may be used in the composting process rather than being recycled. Wood chips are effective bulking agents and can be obtained and delivered free of charge from local arborists and landscapers who must pay to dispose of this waste in landfills. Unfortunately, the supply and regularity of wood chips availability can be variable.

CAPITAL COSTS

Description	Cost	Explanation and source of information
Initial purchase	$67 500	Boyd, personal communication, 2001
Shipping	$ 6 000	
Installation	$ 1 000	
Total capital investment	**$74 500**	

CONTINUOUS COSTS

Description	Cost	Explanation and source of information
Cost of recycling	Minimal*	considered negligable
Number of hours additional labor required	520 hours/yr	based on 10h/wk, Boyd, 2001
Cost of labor (@ $8/hr)	$ 4 160/yr	based on price of labor, Mitchell, 2000
Cost of mechanical maintenance/repair	$ 600/yr	Boyd, personal communication, 2001
Cost of 3 yd^3 waste service 4 times/wk	$ 6 062/yr	Waste Management, 2001
Cost of additional electricity	$ 1 000	Boyd, personal communication, 2001
Cost of additional land use	0	Chevy's has space for four dumpsters
Cost of wood chips/ sawdust	0	arborists give these away free
Total continuous investment	**$11 822/yr**	

CONTINUOUS SAVINGS

Description	Savings	Explanation and source of information
Current waste service expenditures	$23 052/yr	Mitchell, personal communication, 2000
Total continuous savings	**$23 052/yr**	

*Recycling costs are expected to be minimal, and will be considered negligable, as the primary practical barrier to recycling bottles and cans is source separation.

Table 1

A firm should purchase a machine if the present discounted value (PDV) of the stream of net revenues in future periods (derived from the use of the machine) is greater than the actual price (P) of the machine (Nicholson, 1998). Present discounted value allows the firm to take account of the effects of foregone interest (Nicholson, 1998). When PDV > P for

$$PDV = R_1/(1+r) + R_2/(1+r)^2 + \ldots + R_n/(1+r)^n$$

where r is the present interest rate of the loan on the machine, n is the life expectancy of the machine, and R_i is the monetary return in year i, the savings derived from the purchase of the machine will be greater than the investment. This measurement is useful assuming the firm will be in business at least as long as the payback period. This scenario assumes that Chevy's purchases the WEMI unit whose life expectancy is between 20 and 25 years with an estimated interest rate between 10-15%[2], and where R_i is continuous savings minus continuous costs = \$11230/yr (Table 1). For the lower interest loan, PDV > P and the payback period is 12 years. For the higher interest loan, PDV < P. These calculations, however, have been made without the consideration of the monetary benefit potentially derived from sale of the compost product.

If the compost product were sold in bulk, it could fetch a price of \$18-20 per ton. At the rate of approximately 455kg of material exiting the composter per day, an additional revenue of \$3276-3640 could be made without accruing further costs. Including this revenue gives a payback period range of between 8 and 12 years (for the range of interest rates given above). By turning the compost into a value-added product by sifting and bagging it, it could fetch a much higher price, on the order of \$200/m^3. This would add significant labor time, materials and management, however.

The above calculations were done under the assumption that the cost of landfilling does not rise over the lifetime of the machine. It is reasonable to expect that landfilling costs will rise significantly over this time period (Goddard 2000, pers. comm.), and such a rise could shorten the effective payback period considerably.

Ecological considerations for <u>Scenario 2</u>: Pollution associated with landfilling is not avoided completely, but a very small fraction of formerly landfilled waste continues to be landfilled. The use of compost renders the production and application of inorganic fertilizers and mined soil stabilizers unnecessary to the extent that the compost is used in their place. The pollution produced in the production and application of these products is thus avoided.

Social considerations for <u>Scenario 2</u>: The initiation of re-use behaviors, especially in the commercial sector, is valuable in driving the movement of nonsustainable human practices towards sustainable ones.

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[2] This range is considered based on a reasonable assumption of an interest rate offered by a bank to a restaurant for the purchase of capital equipment.

Life cycles of soil amenities Compost is an agricultural and landscaping product that has multiple use values for a single investment. Currently used agricultural and landscaping products and their functions for which compost can be substituted are listed below.

Vermiculite: Vermiculite is mined from large deposits in South Africa, Australia, Russia, Brazil, and in the United States; smaller deposits are found in Montana and North and South Carolina (Brady and Weil, 1999). California agriculture relies on long-distance transportation of this product. Activating vermiculite requires heating the mineral to high temperatures to drive water molecules out as they expand the substance. The heating process consumes fossil fuels and produces greenhouse emissions. Vermiculite pieces are charged, and they restore cation exchange capacity to depleted soil. This product also serves to increase gas exchange in compacted soil. Compost restores cation exchange capacity to depleted soils, and can increase gas exchange when mixed with compacted soils.

Inorganic nitrogen: Inorganic nitrogen is obtained from the atmosphere. Under high temperatures and pressures, gaseous nitrogen, N_2, is fixed with hydrogen from natural gas to produce ammonia gas, NH_3 (Brady and Weil, 1999). This process consumes tremendous quantities of energy. In 1980, global anthropogenic nitrogen fixation was 7^11 kg(N)/yr (Harte, 1988). And an estimated 1985 global greenhouse gas emission from fertilizer use was 1.5 Mt/yr, equivalent to 1 Mt/yr CO_2 emissions (United States Department of Energy 1990). Inorganic nitrogen fertilizers provide a greater amount of immediately available nitrogen to plants, and thus must be applied in a manner timely with stages of plant growth. Inorganic nitrogen fertilizers must be applied year after year. Compost provides less immediately available nitrogen to plants; organic nitrogen must be mineralized by microorganisms in soil. Nitrogen becomes available to plants from compost over several years. Due to the biological mineralization required for compost to provide plants with nitrogen, certain pesticides may not be compatible with compost use.[3]

Phosphorus: Apatitie found in phosphate rock deposits is the primary source of phosphorus fertilizers. Since apatite is extremely insoluble, however, it is treated with sulfuric, phosphoric, or nitric acid to produce materials, such as triple superphosphate, that yield phosphorus in a

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[3] Microorganisms in soil provide the necessary ecosystem function (Miller and Miller 2000) to release nitrogen that can be assimilated by plants. Some pesticides decrease soil microorganism populations and diversity (Altieri 1999) and may interfere with the biological mineralization of nitrogen, and thus with the nutrient bioavailability of compost as plant fertilizer. Further studies are recommended.

readily available form. Phosphate rock deposits are located around the world, especially in Florida, North Carolina, Tennessee, and several western states. Extraction of $PO4^{-2}$ from sediment for fertilizer, detergents, etc. was 0.02*10^12 kg(P)/yr in 1980 (Harte 1988). Compost provides soil with ample amounts of phosphorus.

Potassium: Potassium salts are found in natural geological deposits. Beds of solid salts located deep below the surface of the earth are the primary sources of potassium. Deposits are found in many locations, including sites in Canada, France, Germany, and Russia, as well as in New Mexico. Compost provides potassium, as well as micronutrients to soil.

Ecosystem modeling Toward a goal of ecological, economic and social sustainability, it is useful to mimic natural ecosystems in industry. A natural ecosystem produces no true waste. Most products of biochemical processes are used by organisms that have adapted to exploit their presence. The biosphere is an open energy system that uses solar energy as a renewable source of energy; and it is a closed material cycling system. An "industrial ecosystem" (Graedel and Allenby 1995), analogously, rejects the concept of waste. The term "residuals", rather than wastes, of industrial processes can be used to describe byproducts that are recycled back to their original use or cascaded to some other industrial process as feedstocks (Connelly and Koshland 1997). In this sense, on-site composting of food residuals into a soil conditioner which provides nutrients to food products represents a small-scale industrial ecosystem. Landfilling of food residuals, the widely practiced alternative to composting, leads to the mixing and accumulation of materials and ignores the useful potential of those materials. Landfills have some use potential, however: completed landfills can be landscaped into parks, and, if a landfill is properly equipped, vented methane can be burned for energy. Although a landfill is essentially a giant anaerobic compost pile rich in contaminants, organic materials disposed of in this manner break down to useable forms slowly and contain far too many inorganic contaminants to be useful on a scale relative to human beings. Landfilling indirectly leads to the mining of virgin materials to replace those lost to landfilling, an inherently nonsustainable practice. Landfilling is pollution by accumulation. A waste material must cycle back into its initial use *and quality* to close a material cycle (Connelly and Koshland 1997). Closing of materials cycles is necessary for ecological mimicry to be maintained by an industrial process.

However, for a "waste" stream to become "residuals", energy consumption must also be taken into consideration; specifically, energy must be applied to the consumed material to restore its pre-consumer level of usefulness. An ecosystem is an open energy system; sunlight is its renewable source of energy. It absorbs high entropy energy to drive its metabolic processes. An industrial process, analogously, must apply renewable energy to degraded materials in order to restore them to their initial level of quality, thereby truly closing the material-energy loop. Fossil fuels have served as high entropy energy sources[1] for industrial processes for hundreds of years, but these fuels are non-renewable, and thus represent an open (nonsustainable) material cycle. Composting organic residuals is a cascading process (Connelley and Koshland 1997). The consumed material is not restored, through some mechanical or chemical process, to its original high level of usefulness and quality, e.g. as food for human consumption. It is processed to become the feedstock of a lower industrial process, i.e. fertilization of soil. Such is the nature of the material. This cascaded material can achieve the same useful level of fully recycled material when solar energy drives photosynthesis to convert the nutrients in compost, once again, into food for human consumption.

Thermodynamically speaking, however, composting organic residuals *at the expense of consuming nonrenewable energy* is no more ecologically beneficial than landfilling the waste. The combustion of fossil fuels (and other nonrenewable methods) for energy generation consumes nonrenewable material resources, creates air and water pollution, increases human and ecosystem health hazards and contributes to global warming.

Directing the degraded product into a feedstock for some process other than amending the soil that is the medium for the food growth, e.g. landscaping rather than grain and produce fertilization, fails to tightly close a material-energy loop. Using the compost product for fertilizing grain and produce and for the restabilization of the soil from which they grow most closely mimics the ecological closing of a materials cycle. Nutrients are restored to regenerate food, and physical structure is restored to the soil.   Directing the soil conditioning product to landscaping, however reduces the necessity to use additional materials such as mined vermiculite, chemical fertilizer, fungicides, etc. Furthermore, directing a compost product to any local use, whether it be landscaping, brownfield remediation, etc., stimulates the local economy, reduces environmental and economic costs of transportation, and reduces local dependence on externally produced soil conditioning products. While many of the layers of complexity of the above discussion cannot be represented visually, figures can be drawn to include materials and energy in order to compare their relative basic ecological sustainability.

Figure 2 represents a sustainable system: the system is fueled by renewable energy, and there is a complete cycling of materials.

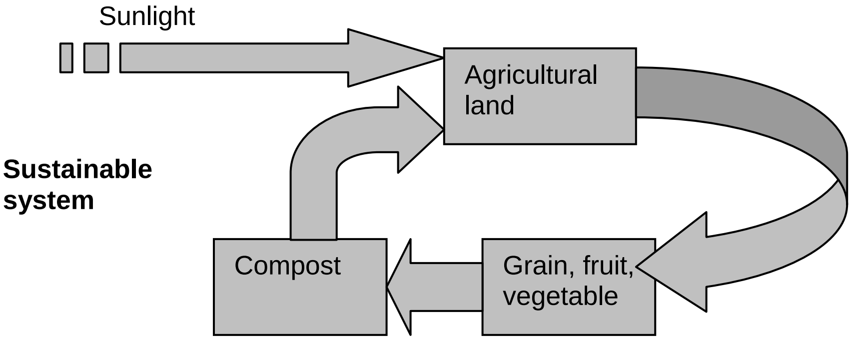

Figure 2 Sustainable system

Figure 3 represents a nonsustainable, waste-oriented system: nonrenewable energy helps fuel the system, and raw materials must be extracted while waste accumulates in a landfill. Over geologic time, one could arguably draw another arrow between the gray box on the bottom right with the gray box on the bottom left, but on any time scale relative to humans, the former represents accumulation and the latter, extraction. The present landfilling waste management system at Chevy's is similar to that in Figure 3. The closer a restaurant can come to Figure 2, i.e. the more closed loops that can be drawn, the more ecologically sustainable

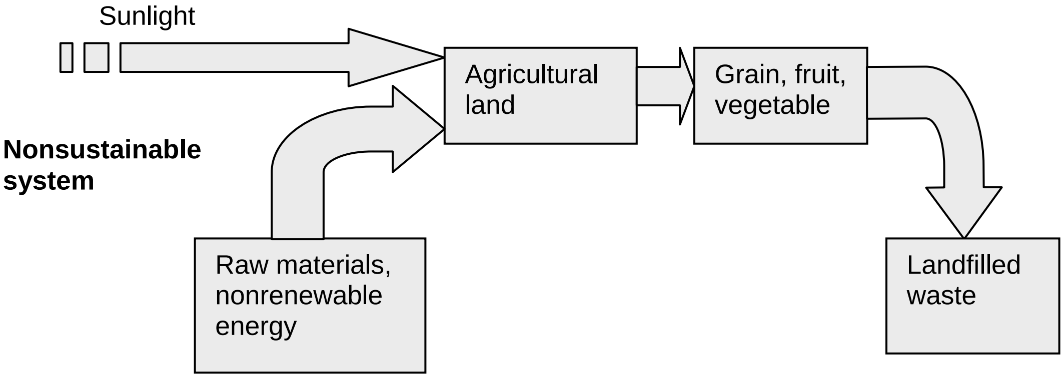

Figure 3 Nonsustainable system

it is. Given today's conditions, Figure 4 represents what on-site composting would look like at Chevy's in Emeryville.

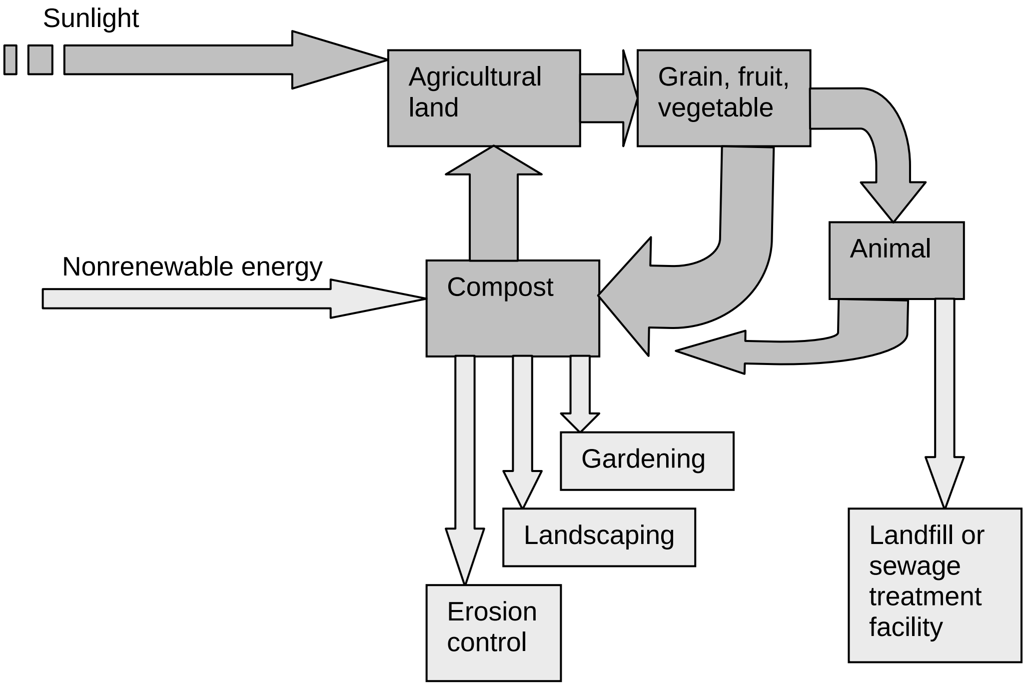

Figure 4

The system is more ecologically sustainable than the present system of landfilling organic waste as evidenced by its closed loops.

Social Considerations Human behavior contributes as much to sustainability as our knowledge of ecosystem science. While composting today may be limited in its ability to use renewable energy as a power source or fully close material cycles, practically speaking, initiating re-use behaviors in industry that are less-than-perfect sets the groundwork for the development of these behaviors into more ecologically sustainable ones.   Integrating re-use behaviors may therefore be the most critical first step to transforming waste-oriented industrial processes into industrial ecosystems. Maintenance of waste behaviors is perceived as a social cost, and development of re-use behaviors is perceived as a social benefit. These behaviors can have long-term effects on society.

Discussion

It was determined that the payback period on the hypothetical capital and continuous investment in on-site composting at Chevy's based on the current price of waste management is between 8 and 12 years. This payback period was calculated with a range of values for interest rates on a capital equipment loan, and a range of values for the market price of bulk compost. In all cases, price for landfilling waste management service was kept constant, a highly unlikely circumstance. Landfilling prices are rising across the country as space becomes scarce and regulations become stricter. It was beyond the scope of this research to determine the projected future landfilling cost. However, a significant rise is expected (Goddard 2000, pers. comm.) and could significantly reduce the payback period for the purchase of a composting machine.

Efforts by government agencies and environmental groups (Goddard 2000, pers. comm.) are focused on the goal of zero landfilled organic waste. The adoption of on-site composting by a restaurant today may prove to be an investment in compliance with future regulations. For single proprietorships, which includes thousands of restaurants in the Bay Area, the cost of the capital equipment for composting can be depreciated over a period of years using Form 4562. For corporations, such as Chevy's, significant tax incentives exist for the purchase of capital equipment. These combined results, fairly short and potentially very short payback period and tax incentives for capital investments, suggest that on-site composting is economically more valuable, especially in the long term, than landfilling organic residuals.

For restaurants to adopt this technology in the near future will require more than just economic incentive; waste-maintenance behaviors are imbedded in business as well as in society. Furthermore, composting in general, and on-site composting in specific, have particular associated constraints. Management constraints present a particularly acute barrier to the adoption of on-site composting in restaurants.

Constraints on the practice of composting Aerobic conditions must be maintained for rapid composting to take place; anaerobic decomposition is lengthy, odorous, produces methane gas, and results in lower available nitrogen concentrations as denitrifying bacteria convert nitrate to molecular nitrogen. Four factors are necessary for aerobic, rapid composting to take place. The composting feed stock must have a mix of organic materials which maintain a sufficient C:N ratio for microbial growth. Oxygen must be present in sufficient quantity over time to support aerobic conditions. An adequate moisture level must be maintained for microbial growth.

Temperature of composting should support thermophillic microbial growth.[2] Compost with glass, metal fragments or plastic contaminants is unfit for land application, and these contaminants must be separated from the composting feedstock (Brandt and Martin 1996). However, sifting the composted product prior to land application can reduce the amount of these inorganic contaminants and increase the quality and marketability of the product. The practice of sifting post composting ensures the removal of durable contaminants likely to enter the feedstock through human sorting error.

Management constraints Significant management constraints potentially exist for the adoption of on-site composting of organic waste by restaurant managers. The following constraint was identified by a corporate manager for the Chevy's restaurant chain (Goodman 2001, pers. comm.): the responsibility of maintenance and repair of the composting machine belongs to the restaurant manager. Landfilling companies provide waste management service which involves reliable and regular removal of waste from the restaurant. Minimal management responsibilities exist compared with on-site composting.

An additional constraint to practicing on-site composting can be space. The WEMI unit takes a 3m (10ft) by 6.7m (22ft) platform, about the size of a parking space, and is 3.7m (12ft) high. It is recommended that 1.8m (6ft) of space be left on each side of the composter to maneuver around it.

Benefits of the practice of composting Management benefits include reduced waste storage time. Waste must be stored for a maximum of two days, three times weekly with landfilling waste management service. In-vessel composters have the advantage of continuous loading capacity, reducing waste storage time to zero. For this reason odor is likely to be reduced with the adoption of on-site composting rather than increased as is often the bias.

Organic matter content in compost ranges from 30 to 50 percent of dry weight, with the remainder being minerals. The application of compost to agricultural land builds the physical structure and enhances cation exchange capacity of soil, increasing its ability to retain water and to avoid leaching nutrients. Furthermore, the addition of compost replenishes organic and inorganic nutrients lost to plant harvesting and erosion. Inorganic fertilizers have a higher macronutrient content per volume, but do not enhance the physical structure of soil. Products that enhance water retention, filtration and cation exchange capacity such as vermiculite do not provide plant nutrients. The combination of high organic content and a variety of minerals makes compost an excellent adsorbent for both organic and inorganic chemicals, making it an effective remediation tool in contaminated sites. Not only does compost enhance the physical and chemical components of soil, but its production and use could divert at least 24.6million tons of solid waste from US landfills annually (EPA 1999), while decreasing the demand for inorganic fertilizers and soil stabilizers. Compost has natural antimicrobial capabilities because of the interspecies competition its microbial populations provide when applied to soil (EPA 1997). Thus, ecological benefits of the use of compost as a soil amendment include: improved physical structure of soil, increased nutrient stocks in soils, increased resistance to wind and water erosion, reduced siltation and nutrient runoff in estuary and groundwater systems, reduction of matter in landfills, reduced demand for inorganic fertilizers, reduced demand for mined soil amenities such as vermiculite, and reduced demand for petroleum based pesticides (EPA 1998, 1997).

Major challenges to the feasibility of on-site commercial composting revealed in this research are (1) overcoming real and perceived management constraints, and (2) lack of information and misinformation about on-site composting. The results discussed in this research project begin to address these challenges.

There exists a significant unexploited market for a middleman firm to enter as an on-site compost facility provider. While the decision to switch to onsite composting as a method of organic residuals disposal in Bay Area restaurants may be hindered by the increased responsibility and management incurred by this vertical integration of sorts, an opportunity for new type of waste management provider has arisen. A middleman firm would, in this case, provide the capital equipment for on-site composting and the services of maintenance/repair of the machine and unloading/hauling of the composted product. These services would be provided at a minimal cost to the restaurant as the waste management firm would reap the benefits of marketing the product. In this way, the economic benefit to the restaurant of on-site composting is maintained, yet it is combined with the same desirable diffused responsibility for management and marketing as off-site composting. This system may represent the best of both worlds, and I recommend that city governments in the Bay Area take advantage of both the unexploited market and the opportunity to provide an environmental service locally and globally.

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