Sustainable Composting Systems: An Organic Waste Management Solution

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ABSTRACT

This paper identifies two problems, (1) the agricultural issue of existing low-value marginal land and (2) the large distance of organic waste transportation as it relates to environmental and economic costs. Using San Francisco as a case study, this paper investigates the transportation of organic waste. However with the current and long transportation distance organic waste must travel to its destination, I examined a new method of carrying this freight. Using the results, this paper suggests transporting organic waste via barges from San Francisco to a new and closer compost facility located near Port Sonoma, off the San Pablo Bay, on the adjacent marginal land. This study specifically addresses the environmental and economic implications of different modes of transporting organic waste and suggests a composting system that will fortify marginal land increase its value. The compost produced on the compost facility can be used to build up the marginal land surrounding Port Sonoma to transform that low-value land into fertile, agricultural land. Several states have established mandates to require the recycling of organic material; this study uses these political movements to bring compost to marginal land. This new composting system is transferable and can be implemented in any cities surrounded by water, allowing for this research on sustainable transportation to spread. Implementing this proposed system of composting, has the potential to shorten the circulation of crops to consumers, transport organic waste a shorter distance, emit fewer GHGs and same some capital.

KEYWORDS

Compost, waste, barge, transfer truck, marginal land

INTRODUCTION

In the United States, there exist large areas of marginal land. Land is considered marginal when it has low value due to a lack of soil nutrients, flood risk, and issues related to erosion, which make it unsuitable for development or agricultural use (Barbier, 1997). Throughout the US, marginal land increases an area's susceptibility to natural disasters and decreases its protection of natural habitats due to the aforementioned issues (Costanza, Mitsch & Day, 2006). However, raising the elevation of marginal land and improving its soil fertility can help to solve the land's problem of low productivity, erosion and flooding.

If the marginal land can be raised and developed into suitable farmland, the life cycle of agriculture crops to consumers could be shortened. If we look at a metropolitan area, we can situate the general circulation of crops to be a closed loop. For example, the farmers grow the crops, the crops are sent to urban areas, the people consume the crops as food, the consumers throw away their food as organic waste, the organic waste is composted and the compost is sent back to the farmers for agricultural uses. If marginal land is improved for agricultural use, it will increase the number of areas where valuable crops can be gown. This could shorten the distance that crops must travel to their point of consumption, making this loop more sustainable**.** To transform marginal land into suitable agricultural land, land owners need to raise the elevation of marginal land so valuable crops can grow.

The development of marginal land into fertile soil can be accomplished using compost, a material generated by processing decomposing organic waste (EPA, 1997). Compost is mixed with dredge from a sediment-filled water source and as the water drains the solids are left behind and begin to build up the land (Stevens, Diamond & Gabor, 2002). Without the compost additive the dredge creates hard soil where only low value crops, such as oat hay, can grow (Stevens, Diamond & Gabor, 2002). However, with the compost additive, the soil created is fertile, has good tilth, and is able to produce valuable agricultural crops (Barbier, 1997). Key to these actions is the issue of how to get the compost to the marginal land.

Several states have implemented diversion mandates to require people to recycle their waste and it's these political movements that can assist in the effort to bring compost to marginal land (Goldstein & Steutville, 2005). In 1989, California established a diversion mandate of 50%, the state surpassed that goal and now cities, like San Francisco, divert up to 77% of their generated waste (Brown, 2007). However, California faces the problem that waste generation is in urban areas and compost facilities are in rural areas. This being the case, the environmental implications and economic costs from hauling this organic waste have become problematic.

This paper focuses on San Francisco, CA, as a case study because of its high profile organic diversion program and the large distance that the waste must travel to reach a compost facility. Currently, the organic waste generated in San Francisco is processed in Vacaville, over sixty miles from the source of waste production (Farrell, 2005). Transfer trucks, also known as 'possum belly' trucks, are the vehicles that transport organic waste. The transfer trucks contribute to both environmental impacts and economic costs that are necessary to consider. The environmental impacts of trucks include greenhouse gas and toxic air contaminant emissions as well as societal disruptions such as traffic congestion, degradation of highway infrastructure and vehicle accidents (EPA, 1997; EPA, 2002; U.S. Department of Transport [DOT], 1994). These environmental externalities help to increasingly exacerbate climate change and the prevalence of respiratory illnesses and premature death, while traffic congestion wastes energy resources and increases the likelihood of accidents (Texas Transport Institute, 2009; Mitchell, Johns, Gregory & Tett, 1995; Brunekreef et al., 1997; DOT, 1994). The primary economic costs associated with trucking organic waste are also important to consider. It is necessary to analyze the primary costs of hauling companies, such as fuel, manual labor and operation and maintenance costs (DOT, 1994). Transportation costs can be calculated as they are related to distance traveled to help determine the expense incurred by both the economic and environmental (GHGs) aspects of organic waste transportation.

An analysis of the current system for managing organic waste in San Francisco has both high environmental and economic costs, however there is an opportunity to create a more sustainable composting process because of the city's proximity to an extensive aquatic system. Instead of trucking the organic waste to the composting facilities, San Francisco could barge it. Previous studies show that barges emit fewer GHG emissions, are more fuel efficient, cause fewer accidents and potentially cost less because they have larger carrying capacities (Texas Transport Institute, 2009). By taking advantage of the waterways surrounding the San Francisco area, barges can transport organic waste to an organic processing facility that can be built on marginal land. Given that there are hundreds of acres of marginal land next to Port Sonoma, just over 35 miles away from the San Francisco waste generation, this paper explores the possibility of building a composting facility next to the port and the facility could fortify the adjacent marginal land with the compost it produces.

This paper identifies two problems:

(1) The agricultural issue of existing low-value marginal land

(2) The large distance of organic waste transportation that leads to economic and environmental costs

Using San Francisco as a case study, this paper evaluates transporting the organic waste via barges from San Francisco to a new and closer compost facility located near Port Sonoma, on the edge of the San Pablo Bay, on marginal land. This study will address the environmental and economic implications of different modes of transporting organic waste and investigate a composting system that will use the compost produced at the new Port Sonoma facility to build up the marginal land next to the San Pablo Bay and potentially shorten the crop to consumer life cycle.

METHODS

Carbon dioxide greenhouse gas calculations

The greenhouse gas (GHG) receiving the most focus around the world today is carbon dioxide (CO_2), so for this study I assessed environmental damage by the tons of CO_2 GHG produced (Texas Transport Institute, 2009). CO_2 GHG emissions were calculated for the truck and barge routes transporting organic waste in San Francisco as a comparative measure of associated emissions. The established truck routes and the barge routes are based on best available road and nautical map data. The truck route begins at the San Francisco transfer station (501 Tunnel Avenue, San Francisco, CA 94134) and ends at Jepson Prairie Organics compost facility (6426 Hay Road, Vacaville, CA 95687). The barge route also originates from the San Francisco transfer station but will end at the potential compost facility located next to Port Sonoma (270 Sears Point Road, Petaluma, CA 94954). Using the Texas Transport Institute average fuel efficiency values (Table 1) combined with the EPA GHG emission parameters for CO_2 (Table 2), I calculated the tons of CO_2 GHG emissions produced round-trip by each mode of transportation for the amount of ton-miles traveled (Texas Transport Institute, 2009).

Table 1. Texas Transport Institute Summary of Fuel Efficiency

Mode of Transportation	Ton-Miles/Gallon
Truck	155
Barge	576

Table 2. EPA Greenhouse Gas Emissions Parameters - CO_2

Diesel Fuel Carbon Weight per US Gallon	2,778 grams (average)/gal
% Carbon (C) oxidized into Carbon Dioxide (CO_2)	99
CO_2 molecular weight (Carbon 12, Oxygen (16x2=32)) 12+32=44, or CO_2 multiplier is =	44/12
CO_2 weight is (2,778x0.99x(44/12))=	10,084 g/US gal
10,084 grams÷453.59 grams per pound=	22.2 lbs/US gal

To perform these calculations I first converted the miles traveled by each mode into ton-miles traveled by multiplying the distance by the amount of tons carried and then divided by the mode's fuel efficiency (Table 1) by the amount of ton-miles traveled to find the number of gallons of diesel fuel consumed. Next, for the trucks only, I calculated the number of truck trips it would take to transport the 1,750 tons by dividing the total tons being transported by the number of tons a truck can carrying in one trip. Then, by multiplying the gallons by the number of trips, I calculated the total number of gallons needed to transport 1,750 tons by truck. I must note that the previously mentioned step is not needed for the barge calculations because the barge can transport 1,750 tons of organic waste in one trip. For both modes I multiplied the total number of gallons consumed by the pounds of CO_2 GHG per gallon (Table 2). Lastly, I divided the pounds of CO2 GHG by 2,000 pounds to find the total tons of CO2 GHG produced for each mode's transportation of 1,750 tons of organic waste. For the empty back haul, on the returning trip, I used the average fuel efficiency for each mode provided by the Texas Transport Institute (2009).

Primary economic cost calculations

I calculated the primary economic costs of trucking and barging 1,750 tons of organic waste to their respective facilities. Economic costs associated with the transportation of organic waste are calculated using primary costs, which include labor, fuel and maintenance. The cost of transporting via truck is based on hourly wages of truck drivers, price per gallon of diesel fuel, the amount of fuel required to transport waste from transfer station to compost facility, and the operation and maintenance costs per mile of heavy-duty trucks.

The primary economic costs of transporting organic waste via barge are calculated through the tugboat contract costs. The tugboat contract cost, which is paid each time the barge is moved, is an $800 hourly rate that includes the cost of fuel and labor to push the barge transporting organic waste (personal conversation, Port Sonoma, 4-18-2011). Given that the loaded barge is pushed at 6 knots, the empty barge is pushed at 8 knots and adding 15 minutes at each end for docking I calculated the total amount of time needed to transport the organic waste from the SF transfer station to the Port of Sonoma and multiplied that time by $800 (personal conversation, Port Sonoma, 4-18-2011). The total round-trip economic cost of barging 1,750 tons of organic waste is compared to the total round-trip economic cost of trucking it.

RESULTS

Carbon dioxide greenhouse gas emissions

Heavy-duty trucks produced 11 times the amount of CO_2 GHG emissions than the barge, on a gallon of diesel per ton of compost basis, to their respective facilities. Trucks produce 13.64 tons of GHG emissions roundtrip to transport 1750 tons of organic waste from the transfer station to the Vacaville compost facility and the barge produced 1.23 tons of GHG emissions roundtrip to transport the same amount of organic waste from the transfer station to the Port Sonoma compost facility (Fig. 1)[1].

[1] The organic transport capacity of 1 barge = 70 trucks

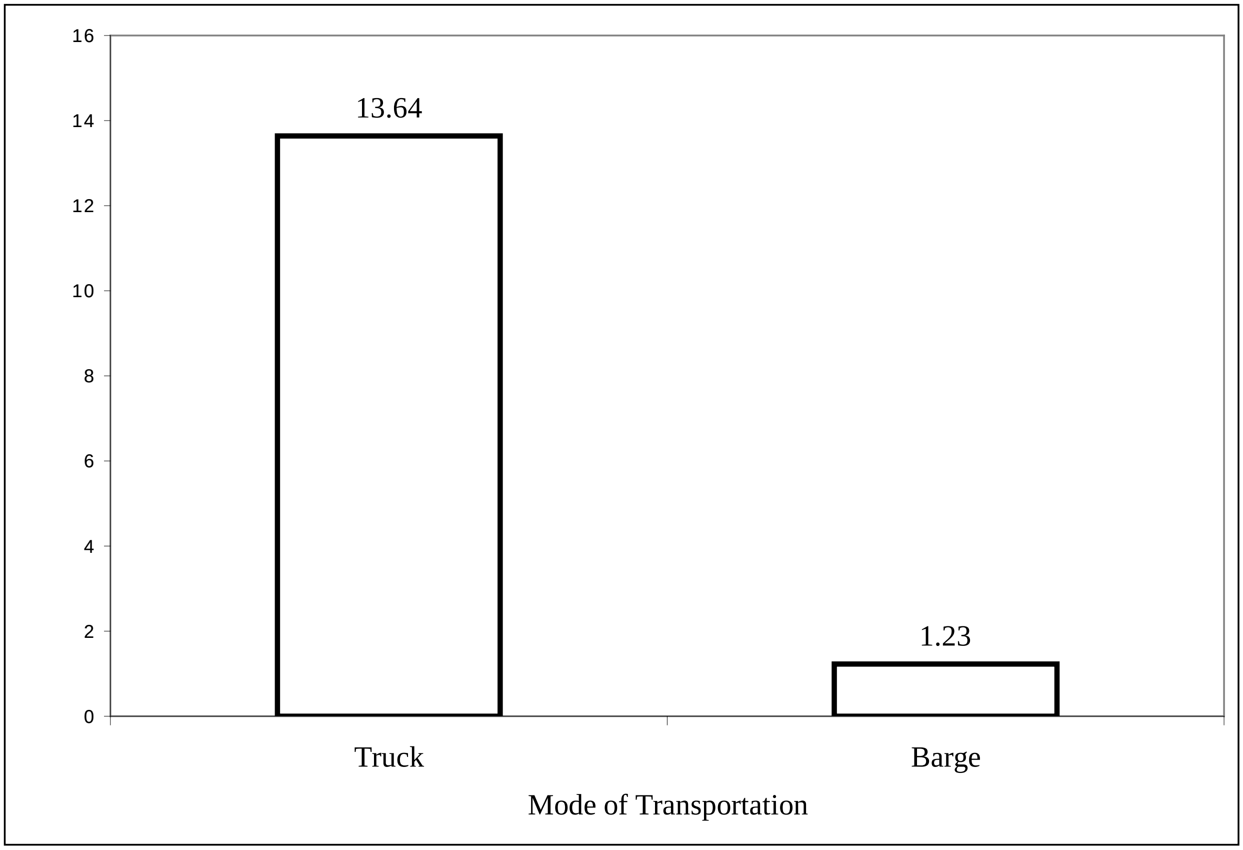

Figure 1. Tons of GHG Produced to Transport 1750 tons of Organic Waste. Note that the above values reflect the distance traveled to each mode of transportation's respective destination: trucks to Vacaville and barges to Port of Sonoma.

Primary economic costs

The total cost for trucking 1,750 tons of organic waste, from the San Francisco transfer station to the Vacaville compost facility, cost $9,158.13 while the total cost for barging the waste, from the transfer station to the Port of Sonoma, cost $8,000 (Table 5). After converting knots to miles per hour, so the time can be evaluated on an hourly basis, I found it takes 10 hours to transport the organic waste by barge. For trucking the organic waste round trip from SF to Vacaville, it took a total of 175 hours, 1,228.77 gallons of diesel fuel and 134.4 miles (Table 3). More specifically, given the labor cost, fuel cost and operation and maintenance cost (Table 4), I calculated that for trucking the organic waste round trip, the labor cost $3,302.25, the fuel cost $4,915.08, and the maintenance cost $940.80 (Table 5) (Bureau of Labor Statistics, 2009; U.S. Energy Information Administration, 2011; Bureau of Labor Statistics, 2010).

Table 3. Round Trip Components of Trucking and Barging Organic Waste. Note that for barges the fuel consumed and hourly wages are included in the tugboat contract cost, so are not listed in Table 3.

Truck		Barge	
Total Hours traveling	175	Total hours traveling	10
Total fuel consumed (gallons)	1228.77		
Total miles traveled	134.4		

Table 4. **Monetary Components of the Cost Comparison of Trucking and Barging Organic Waste**

Truck		Barge	
Hourly Labor Cost	$18.87	Tugboat Contract hourly costs	$800
Fuel Cost per Gallon	$4.00		
Operation and Maintenance Cost per mile	$0.10		

Table 5. Total Costs of Trucking and Barging 1,750 tons of Organic Waste.

Truck		Barge	
Total labor cost	$3,302.25	Total Contract cost	$8,000
Total fuel cost	$4,915.08		
Total operation and maintenance cost	$940.80		
Total Cost	$9.158.13	Total Cost	$8,000

DISCUSSION

This project used San Francisco as a case study to evaluate a new method of organic waste transportation that can transform marginal land to valuable agricultural land. The study found that the economic and environmental costs are fewer if barges transport organic waste instead of trucks. The study also found that using compost to build up marginal land could create areas of suitable farmland that can be used to grow agricultural crops and potentially shorten the crop cycle from the farmers to the residents. Overall, implementing the system of composting this paper examines, has the potential to shorten the circulation of crops to consumers, transport organic waste a shorter distance, emit fewer GHGs and same some capital.

Transportation

Environmental implications

This study showed that barging 1,750 tons of organic waste requires fewer trips than trucking it and, in relation to this study, equates to fewer CO_2 GHG emissions. The Texas Transport Institute (2009) found that, of the popular methods of freight transportation, trucks contribute to the most environmental costs followed by railroads and then by barges and that for every million ton-miles each mode travels, trucks emit 71.61, trains emit 26.88 and barges emit 19.27 tons of CO_2 GHG. My study agreed with the Texas Transport Institute (2009) and concurred that trucks contribute to more environmental costs than barges. Other studies have shown that further GHGs are reduced as compost, created from organic waste, returns to the soils on farms to grow cover crops (Brown, 2007). Previous studies have found these compost-grown cover crops create a carbon sink as they draw in carbon from the air, and that applying compost to one acre of land can sequester 12,000 pounds of compost in a year (Lal, 2004). This means that 100,000 tons of compost, produced annually at a typical compost facility, could equate to offsetting over 300,000 metric tons of carbon emissions on agricultural land (Glenn & Goldstein, 1999; Favoino & Hogg, 2008). These GHG emissions will continue to decrease, as many studies have suggested, as California strives toward its zero waste goal and diverts more organic waste from landfills (City and County of San Francisco, 2009). By diverting organic waste to composting facilities and away from landfills, GHG emissions are reducing (Ehrig, 1983). Organic waste that decomposes anaerobically in landfills produces more GHG emissions that organic waste that is aerobically processed at compost facilities (Belevi & Baccini, 1989; Ehrig 1983). As stated in several previous studies, reducing GHG contributes to slowing the impact of climate change and as society continues to use composting as a way to fight climate change this barge transportation system can positively contribute (EPA, 2009; Barrow, 2003; Houghton, Jenkins & Ephraums, 1990; Mitchell, Johns, Gregory &Tett, 1995). Noticing all these ways

GHGs are currently and can potentially be mitigated, if barges are used to transport organic waste and other types of freight, GHG emissions will continue to drop.

Economic costs

My analysis found that barging organic waste has fewer economic costs than trucking. When costs of labor, distance traveled, fuel and maintenance are taken into account, barging organic waste is cheaper because less is spent on manpower, fewer trips are made and more can be transported for equivalent amounts of fuel consumed. Although this study shows the benefits of barging freight, trucking has become the first choice of a transportation option, because it has existing infrastructure and thus, many of its costs are hidden. Citizens pay taxes to maintain highways and roads and to employ service workers for accident clean up; therefore haulers are not responsible for the full price of truck transportation (US DOT, 1994). So if barging can be utilized to a stronger degree, fewer trucks will be on the road, less damage will be done to the highways and the probability of accidents will decrease (EPA, 1997; US DOT, 1994). Also with fewer trucks contributing to the aforementioned issues, less money is spent on maintenance and clean up.

Additional costs

Trucks also incur costs to the health of people. Heavy-duty trucks emit particulate matter that causes asthma, lung diseases, premature deaths and poor air quality (Kleeman, Schaucer & Cass, 2000; Brunekreef, Janssen, de Hartog, Harssema, Knape & van Vliet, 1997). Although tugboats use the same diesel fuel to push barges as trucks use, this study shows barges emit fewer GHG, so it is the hope that barges also emit fewer toxic emissions and therefore are less costly to society, but more research needs to be done to confirm. The heavy-duty trucks also cause traffic congestion and safety hazards. Traffic congestion wastes energy resources, slows societal productivity, damages the environment and, again, increases the likelihood of accidents (DOT, 1994). The trucks contribute to big accident pile-ups and oil or gas spills which are dangerous safety hazards on the road (Texas Transport Institute, 2009). This new barge transportation system can be used for transporting other types of freight in addition to organic waste and if that is considered then perhaps these societal costs that include pollutants, accidents, traffic and poor environmental quality will decrease.

Marginal land

Currently, off the edge of the San Pablo Bay, the marginal land can only produce oat hay, which is most often used for feed and is not a valuable crop (Hornberger, Luoma, van Green, Fuller & Anima, 1999; Barbier, 1997). However, many acres of marginal land, if treated with compost, have the potential to produce valuable crops such as fruit trees, tomatoes, grapes and more (Barbier, 1989). To improve the marginal land, compost can be used to raise the land elevation and create suitable farmland conditions needed to grow valuable crops. If this method is put into use, there are approximately 600 acres of marginal land near the San Pablo Bay that have to potential to produce valuable crops with the fortification of processed organic waste generated by San Francisco (David Zilberman, unpublished data, 2011). Using Professor Zilberman's calculations and assuming a 600 acre land area and 100,000 tons per year that a typical compost facility produces, to raise the marginal land near Port Sonoma to a suitable farming state, it would take about 30 years. (David Zilberman, unpublished data, 2011; Glenn & Goldstein, 1999; Brown 2007). Though this may seem like a long period of time, we must weigh the benefits of the GHG reduction, cost savings and potential to have sustainable agriculture against the benefits and shortcomings of the current composting and agricultural systems.

In the case of San Francisco, creating suitable farmland on the existing marginal land could shorten the agricultural cycle of food. The organic waste would travel a shorter distance to reach the compost facility, and then the compost could be used to grow valuable crops near the compost facility. This way, these crops have the potential to travel a shorter distance to reach the consumers of San Francisco, because they are grown closer to the city. Previous studies have shown that marginal land increases an area's susceptibility to natural disasters and habitat degradation, but this study suggests that compost can be a solution to these problems (Barbier, 1997; Costanza, Mitsch & Day, 2006). If compost, combined with dredged material, is used to replace the sediment lost by marginal lands, then the marginal land can be strengthened to better withstand disasters and house species (Costanza, Mitsch & Day, 2006).

Limitations

This study excluded analyses of secondary economic cost, the potential loss in truck labor and assumed farmers would choose the most sustainable route for their crops. The study did not conduct a secondary economic analysis, which would have included costs to citizens for necessities like highway maintenance, accident clean up and medications for health issues resulting from truck or barge pollutants. I also did not determine the potential loss of truck labor that could have resulted from switching from truck transportation to the barge system of transportation. Lastly, this study assumes that crops grown on the marginal land would go to the nearest city, however agricultural economics are often times more complicated than that. The crops grown on the San Pablo marginal land could go down to southern California or out of state, depending on what is the best economic move for the farmer.

Future directions

Assessing both the environmental and economic costs of transporting organic waste as well as the opportunity of transforming marginal land is a step toward developing sustainable transportation and sustainable agricultural systems. We need to recognize that there is current infrastructure set up in San Francisco to transport organic waste and it will take time and cost money to create a new barge system, build new compost facilities, gain access to appropriate permits, and create the necessary partnerships and policies to implement the proposed system. However, these hurdles define areas in which further research can be done to help society move toward more sustainable transportation methods, like this paper suggests. Research that investigates the costs of building and the permitting of new compost facilities versus those costs saved by using this new method can further the process of moving toward sustainable composting systems. Also studying the partnerships between haulers, compost facility operators and harbor masters as well as the policies needed to push society to move toward processes of sustainable transportation are great starting points for future research.

Broader implications

This new composting process can be implemented in other cities that, similarly to San Francisco, are surrounded by navigable water. For example, the larger Bay Area, including Alameda, Contra Costa, San Mateo and adjacent counties, is surrounded by waterways and could transport organic waste via barges to the marginal land near Port Sonoma. Also, Seattle, though not near marginal land, is a midst the Puget Sound, Lake Union and Lake Washington and could use the barge transportation system to carry organic waste and any other type of freight. Additionally, New Orleans, surrounded by the Mississippi and Lake Borgne, is a perfect candidate for this suggested organic waste barge transportation system. Moreover, New Orleans has acres of marginal land that could be built up and fortified with compost to transform it into valuable agricultural land. This proposed composting system is transferrable and could make a difference in the environmental and economic costs of transportation.

ACKNOWLEDGEMENTS

I would like to thank my advisor, Thomas Azwell, for helping me throughout the whole process of writing my senior thesis. Thomas helped me develop the idea and worked with me weekly to gather data, organize data, calculate GHGs and economic costs, organize my paper and create my senior thesis presentation. I could not have properly written or adequately completed my thesis project without Thomas' input. I would also like to thank the professors, lecturers and graduate students of ES 196 (Kurt Spreyer, Patina Mendez, Seth Shonkoff and Lara Roman) for assisting my peers and me through the process of writing our first thesis. Lastly I would like to thank my family for supporting me while I worked to create "Sustainable Composting Systems: An Organic Waste Management Solution".

REFERENCES

Barbier, E. (1997). The economic determinants of land degradation in developing countries. *Philosophical Transactions of the Royal Society: Biological Sciences, 352*(1356), 891-899.

Barbier, E. (1989). Sustaining agriculture on marginal land: a policy framework. *Environment: Science and Policy for Sustainable Agriculture, 31*(9), 12-16.

Belevi, H., & Baccini, P. (1989). Long-term behavior of municipal solid waste landfills. *Waste Management & Research, 7*(1), 43-56.

Barrow, M. (2003). An economic analysis of the UK landfill permits scheme. *Fiscal Studies, 24*(3), 361-381.

Brown, M.R. (2007). California links organics recycling to sustainable future. *Biocycle, 48*(6), 20-22.

Brunekreef, B., Janssen, N. A. H., de Hartog, J., Harssema, H., Knape M. & van Vliet, P. (1997). Air pollution from truck traffic and lung function in children living near motorways. *Epidemiology, 8*(3) 298-303.

Bureau of Labor Statistics. (2009). Occupational employment and wages, May 2009. *United States Department of Labor.* Washington DC.

Bureau of Labor Statistics. (2010). Occupational outlook handbook, 2010-11 edition. *United States Department of Labor.* Washington DC.

City & County of San Francisco. (2009). Mandatory recycling and composting. (801404). San Francisco. 1-25.

Costanza, R., Mitsch, W. & Day, J. (2006). A new vision for New Orleans and the Mississippi delta: applying ecological economics and ecological engineering. *Front Ecology Environment, 4*(9), 465-472.

Ehrig, H. (1983). Quality and quantity of sanitary landfill leachate. *Waste Management & Research, 1*(1), 53-68.

Farrell, M. (2005). Vineyards make switch to “four course” compost. *Biocycle, 46*(2), 33.

Favoino, E., & Hogg, D. (2008). The potential role of compost in reducing greenhouse gases. *Waste Management & Research, 26*(1), 61-69.

Glenn, J. & Goldstein, N. (1999). Food residuals composting in the U.S. *Biocycle, 27,* 30.

Goicochea, J. (2009). Ohio supermarket of composting. *Biocycle, 50*(10), 18-20.

Goldstein, N., & Steutville, R. (1996). MSW composting in the United States. *Biocycle, 37*(11), 46.

Hornberger, M., Luoma, S., van Green, A., Fuller, C. & Anima, R. (1999). Historical trends of metals in the sediments of San Francisco Bay, California. *Marine Chemistry, 64*(1-2), 39-55.

Houghton, J.T., Jenkins, G.J. & Ephraums, J.J. (1990). Climate change: the IPCC assessment. *Cambridge, U.K.:* Cambridge Univ. Press.

Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security, *Science, 304*(5677), 1623-1627.

Kleeman, M., Schaucer, J. & Cass, G. (2000). Size and composition distribution of fine particulate matter emitted from motor vehicles. *Environmental Science & Technology, 34*(7), 1132-1142.

Mitchell, J. F. B., Johns, T. C., Gregory, J. M., & Tett, S. F. B. (1995). Climate response to increasing levels of greenhouse gases and sulphate aerosols. *Nature, 376*(6540), 501-504.

Stevens C., Diamond, A. & Gabor, T. (2002). Anuran call surveys on small wetlands in Prince Edward Island, Canada restored by dredging of sediments. *Wetlands, 22*(1), 90-99.

Texas Transport Institute (2009). A modal comparison of domestic freight transportation effects on the general public. Houston.

U.S. Army Corps of Engineers, Institute for Water Resources (2008). Waterborne transportation lines of the United States. (Vol 3). Alexandria.

U.S. Bureau of the Census. (2010). Demographic research unit, California Department of Finance. Land Area.

U.S. Department of Transportation, Maritime Administration (1994). Environmental advantages of inland barge transportation.

U.S. Energy Information Administration. (2011). Gasoline and diesel fuel update. *U.S. Department of Energy*. Washington, DC.

U.S. Environmental Protection Agency (1994). Composting yard trimmings and municipal solid waste. (EPA530-R-94-003).

U.S. Environmental Protection Agency (2002). Diesel exhaust in the United States. (EPA420-F-02-048).

U.S. Environmental Protection Agency (1997). Emission standards reference guide for heavy-duty and nonroad engines. (EPA420-F-97-014).

U.S. Environmental Protection Agency (2009). Municipal solid waste generation and disposal in the United States: facts and figures for 2008. (EPA-530-F-009-021). Washington DC.

U.S. Environmental Protection Agency (2004). Update of methane and nitrous oxide emission factors for on-highway vehicles. (EPA420-P-04-016). Office of Transportation and Air Quality.