Composting at Skidmore College: Turning our Waste into a Resource

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INTRODUCTION

Everyday, Skidmore College produces thousands of pounds of waste output in the form of horse manure, food scraps and lawn-maintenance byproducts, contributing to an ongoing dilemma of how waste should be disposed of in America. Addressing the management of organic waste at Skidmore is embedded in a broader environmental context of increasing amounts of waste; over 250 million tons of municipal solid wastes will be generated in the US in 2010, 10.9% will be food waste and 12.1% will be yard wastes, and all organic wastes will comprise about a quarter of all landfill waste (EPA 2010).

Disposal of organic wastes in landfills is a costly process. Organic wastes contaminate water supplies, generate greenhouse gas emissions, convert large amounts of land into virtually unusable space, and interrupt natural nutrient cycles on which ecosystems depend. The Environmental Protection Agency (EPA) estimates the total cost of municipal waste disposal is $100 per ton; therefore, the total cost of municipal waste disposal in the U.S. is about $25 billion. The U.S. has 3,091 active landfills and over 10,000 inactive municipal landfills; according to the EPA they will all eventually fail and leak. When landfills leak, nutrient-rich leachate enters water bodies and contributes to cultural eutrophication. Methane, a greenhouse gas 72 times more potent than carbon dioxide, is generated in landfills as organic waste decomposes under anaerobic conditions. Landfills are the second largest anthropogenic source of methane in the U.S., creating 23 % of all methane emissions (EPA 2010). Conventional waste management practices interrupt natural carbon, nitrogen and phosphorous cycles that are essential in maintaining balanced ecosystems.

These organic wastes, rather than being an environmental and economic problem, are capable of being converted into an environmental and economic asset through composting.

Composting systems embody both a symbolic and practical response to the unsustainable practice and philosophy surrounding US waste disposal methods of the 20th century. Composting is a means of converting organic waste material, such as food scraps, yard waste and manure, into a substance called humus, a nutrient-rich soil amendment. Humus is an essential element in maintaining healthy soil and plant life, making composting a useful tactic for nurturing productive agricultural fields, ornamental plants and grasses (Rynk Chapter 1, page 2-6). Apart from the global movement toward more sustainable societies, in the context of Skidmore, composting is about saving money by addressing our current waste inefficiencies, creating a revenue-generating product out of our campus's three waste streams, and substantiating the College's reputation as an environmentally aware and sustainable institution. In addition, composting at Skidmore is about reducing campus water use in the disposal of food wastes, and thereby taking on our College's responsibility to conserve the water resources of the greater Saratoga community.

Goals:

This study seeks to explore the economic and environmental costs and benefits of implementing a comprehensive composting system that processes Skidmore College's three organic waste streams: food waste, lawn-maintenance byproducts and horse manure. A composting system could benefit the College by decreasing disposal costs and water consumption, while also reducing the environmental impact and carbon footprint of the College. In addition, the three waste streams have the potential to both provide for a portion Skidmore's on-campus fertilization needs and to become a revenue-generating product. This paper explores the feasibility of implementing a windrow composting system at Skidmore under three different scenarios. With their associated costs and benefits, the scenarios are meant to be a template for presenting the variety of options that Skidmore has in creating a composting system, and can be combined, reformed or implemented consecutively in the event that the Skidmore Community does decide to compost its organic waste. This study aims to demonstrate how Skidmore can financially, environmentally and educationally benefit from the implementation of a windrow composting system.

Background – Organic Waste at Skidmore College

Skidmore is a residential college of 2,400 students in Saratoga Springs, NY. In recent years, the school has pursued a variety of programs to increase the schools sustainability and decrease its environmental impact. For example, the school has an extensive recycling program (of plastic, glass, and paper products), is currently undergoing a greenhouse gas inventory, and has invested in renewable geothermal heating and cooling (Sustainable Skidmore). Composting at the College offers an opportunity to further the community's environmental efforts while also investing in a cost-effective long-term waste management strategy. Each year, Skidmore produces approximately 3,650 cubic yards of horse manure, 666 cubic yards of lawn waste, and 205 cubic yards of food waste, for a total of 4521 cubic yards of organic waste a year. These organic waste streams place both a financial burden on the College and raise questions regarding the environmental sustainability of its operations.

Horse Manure:

Horse manure is an ideal composting material, and is frequently used to make high quality compost, such as that for growing edible mushrooms (Rynk 16). The term 'horse manure' refers to not only the fecal matter produced by the horse, but also the bedding. At Skidmore, the horse stalls are bedded with fresh pine wood chips, which make up approximately half of the waste material (Cindy Ford, Personal Communication). The combination of carbon rich bedding and nitrogen rich fecal matter create an ideal carbon-nitrogen ratio for composting. A 1,000 pound horse generates eight to ten tons of manure per year, accumulating at a rate of two cubic feet per day. A ton of fresh manure may contain approximately 13 pounds of Nitrogen (as N), 5 pounds of phosphorus oxide (as P_2O_5), and 13 pounds of potassium oxide (as K_2O) (Romano 2005).

The 30-year old Van Lennep Riding Center is one-half mile away from the College in a rural location in the town of Greenfield, NY. It is home to approximately 30 Skidmore owned horses, has the capacity to board an additional 37 student-owned horses, and currently boards an average of 60 horses year round. Horse stalls are bedded with fresh pine chips and the horse manure is approximately 50 percent feces and 50 percent bedding.

While the stables are a valuable part of Skidmore, the waste stream created by the Van Lennep Riding Center has created environmental and economic issues for the College. For many years, a combination of manure, stall bedding, and other stable waste was dumped behind the Van Lennep facility. While this strategy was economically cheap, it resulted in the leaching of nutrients and waste materials into an adjacent pond, and into the greater Kayaderosseras Creek Watershed. Currently, Skidmore pays the firm Springer Waste Management to haul the stables horse manure to a large scale composting site. The cost of this disposal is $165.00 per 30 cubic yard container, which is usually filled every three days (Cindy Ford, Personal Communication). Skidmore College spends approximately $20,065.00 to dispose of 3,650 cubic yards of horse manure per year. While this policy minimizes the environmental impact of stable waste on the local area, it is an economically costly solution for the College, and rather than taking an advantage of an available resource, it sends it to a firm that produces a value-added product for itself.

In addition, a substantial amount of human labor is required to clean manure from stalls and transport it to the holding container that Springer ships away. Four Van Lennep Riding Center employees (3 employees on weekends) spend around 5 hours per day mucking out stalls, placing the manure in buckets, moving it with a farm tractor (John Deere Tractor, LV5300E430371 1994), and then manually lifting it over a six feet height into the holding container. Composting would substantially decrease the amount of labor required to clean stalls and to transport manure. Instead of transporting and lifting manure into the Springer Waste holding container, manure could be collected in the stables dump wagon and driven to the compost site, without a need for collecting the manure in buckets and manually lifting it into the holding tank. In short, composting behind the Van Lennep facility could significantly decrease the amount of time necessary for cleaning the horse stables while also decreasing the occupational hazards of repetitive heavy lifting (Cindy Ford, Personal Communication).

<u>Food Waste</u>:

Skidmore College produces a substantial amount of food waste from the campus's main dining facility, the Murray-Aikens Dining Hall. A 2009 waste audit of the Dining Hall concluded that an average of 575 pounds of waste (172 lbs pre-consumer and 403 lbs post-consumer) is produced on weekdays and 509 pounds of waste (170 lbs pre-consumer and 339 post-consumer) is produced on weekend days (Whately 9). Assuming that the facility is open 329 days a year (230 weekdays and 99 weekend days), and that waste production is constant throughout the operating year, the Murray-Aikens Dining Hall produces 182,641 lbs of food waste each year. Pre-consumer waste comprises 56,390 lbs, or 30.8%, of this weight and post-consumer waste is 126,251 lbs, or 69.2%. Using a weight to volume conversion of 5 gallons = 20.6 lbs[i], it is

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[i] To arrive at this conversion, we weighed a 5 gallon bucket of pre-consumer food waste from Emily's Garden and a 5 gallon bucket of post-consumer food waste in the dish room of the Murray-Aikens Dining Hall.

estimated that the dining hall alone produces 205 cubic yards a year. Currently, post-consumer food waste is disposed of by means of a trash disposal and flushed down the drain, while pre-consumer food waste is put in the trash and is disposed of in a landfill (Cherry, Personal Communication).

Pre-consumer waste, such as vegetable scraps, is disposed in trash cans that are placed throughout the dining hall kitchen area. It, along with all other trash, is then placed in a dumpster where it is collected daily by Springer Waste Management. Skidmore College currently pays a hauling fee of $105 per haul and then $69 per short ton of municipal solid waste (Erica Fuller, Personal Communication). The diversion of all pre-consumer organic waste would decrease the amount of municipal solid waste by 28.195 short tons per year, but would not decrease the number of hauls. Therefore, the diversion of 100% of pre-consumer waste would yield a savings of $1945.45 per year. A more conservative estimate of 80% diversion would yield a savings of $1556.36 per year. The diversion of food waste would also decrease the College's carbon footprint by decreasing the amount of landfill methane emissions.

Post-consumer food waste travels linearly through garbage disposal and pipe to Saratoga County's Waste Water Treatment plant, where it is dried and incinerated. In addition to wasting large amounts of water, this practice uses high amounts of fossil-fuel based energy for the process of incineration. According to an EPA study, the gross green house gas (GHG) emissions from the municipal solid waste combustion of food waste is 0.02 metric ton carbon equivalent (MTCE) per metric ton of waste (EPA 2005). Considering that Skidmore produces about 40 metric tons of post-consumer waste a year, the current disposal of food waste produces approximately 1.8 MTCE emissions each year, equivalent to the yearly emissions of 1.2

vehicles. Conversely, if the same amount of food waste were composted, it would yield a net greenhouse gas reduction of 6.3 MTCE per year, equivalent to taking 4.2 vehicles off the road[ii].

The garbage disposal used in the dining hall to shred the food waste and send it into the sewer system uses a substantial amount of water, contributing to the College's water footprint and the stresses on local water supplies. The current food waste disposal method uses 3,993,402 gallons of water a year, which comprises nearly 10% of the College's water use and costs the school approximately $800 a year.[iii] Switching to a composting system would substantially reduce these costs, saving the college money while also decreasing our carbon and water footprints.

Lawn Waste:

Skidmore's lawn maintenance by-products, such as leaves, grass-clippings and branches, are currently piled behind the Van Lennep facility—an ideal site for a large-scale composting operation, as will be explained later. While simply dumping these yard wastes causes no significant environmental or economic setbacks to the College, the practice does not utilize the potential these materials have to become a revenue-generating product. Because of the high carbon content that is typical of yard waste, this waste stream could, in combination with the nitrogen-rich food and horse wastes, reasonably create a favorable carbon-nitrogen ratio for composting.

Lawn waste is transported from the College to the stables in a truck bed that is 7.5' wide, 8' long and 4' high, with a capacity of 8.88 cubic yards. Large pieces of debris are ground up by a tub grinder before being loaded onto the truck. Approximately 25 truckloads of lawn waste, or

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[ii] U.S. EPA 2007. Annual emissions of typical passenger vehicle = 1.5 metric tons of carbon equivalent

[iii] Assuming that the disposal uses 867 gallons of water per hour. This was extrapolated from an experiment filling the disposal and calculating its volume. It assumes the disposal runs for an average of 14 hrs/day, 329 days operating days/year and a cost of .02 cents per gallon (or $.0002 per gallon). This results in 3,993,402 gallons/year at a cost of $798.7/year.

222 cubic yards is produced every Spring and 50 truck loads, or 444 cubic yards is produced every Fall, for a total yearly yard waste production of 666 cubic yards (Erica Fuller, Personal Communication). Since this waste stream already is already regularly transported to the site behind the Van Lennep facility, it is likely that the same equipment and a similar amount of labor could be utilized to transport the food waste as well.

METHODS

This feasibility study combined information obtained from personal interviews with relevant stakeholders, research of literature on the topic and investigations of peer institutions that compost. A significant portion of the research was logistical, relying on interviews with staff from the Dining Hall, Facilities and the Van Lennep Riding Center, in order to ascertain how Skidmore would realistically implement a composting system.

The Skidmore data was obtained through personal interviews with:

- Erica Fuller—Campus Sustainability Coordinator
- Cindy Ford—Director of Van Lennep Riding Center (stables)
- William Canney, Jamie Cherry and Jim Rose—Dining Services staff
- Paul Lundberg and Brian Wimble—Facilities
- Anthony “Skip” Scirocco—Saratoga Springs Commissioner of Public Works

Skidmore data includes the current costs of organic waste disposal (from horse stables, dining hall, and grounds), the amount of organic waste the school produces, fertilizer expenses, the time spent managing organic waste, space available for a composting system, and the opinions of key stakeholders in the process, such as the above interviewees. Scientific information was obtained from peer reviewed journals, such as Biocycle, books published on the subject, and guides written by cooperative extensions. Scientific information includes the ideal inputs for compost, conditions necessary to kill pathogens and create a nutrient-rich compost, and potential problems with nutrient runoff and pest infestation. Technical data on composting systems available was obtained from company websites, publications, and conversations with representatives. Technical information on composting system includes the cost, availability, operating hours required, space and infrastructure needs, and type of waste that can be used. Information regarding the operation of similar composting systems at peer institutions was obtained from websites, publications, conversations, and site visits at Middlebury College and Smith College.

COMPOSTING TECHNOLOGIES

What is Compost?

Composting is a means of converting organic waste material, such as food scraps and manure, into a valuable nutrient source and soil amendment, a substance known as humus. Humus is characterized by having short molecular chains and provides fertility to the soil by retaining moisture, forming good soil structure and containing the basic nutrients of a healthy soil (Modern Composting Technologies). Humus is an essential element in maintaining healthy soil and plant life, making composting a useful tactic for nurturing productive agricultural fields, ornamental plants and grasses.

Composting is carried out by various types of microorganisms, including bacteria, fungi, actinomycetes, algae, and protozoa. These aerobic microorganisms convert organic material and oxygen into compost, carbon dioxide, nitrate (NO^-_3), sulfate ($S0^{2-}_4$) , and heat (Chiumeti). In forest ecosystems, decomposition of organic matter naturally produces humus, which cycles nutrients and makes them available for plant life that are in turn available for animal consumption and, in turn, the entire food chain. Composting is a balanced and human-controlled biological process, based on this natural nutrient cycling.

Conditions:

There are a number of factors that contribute to the creation of healthy compost. These include oxygen levels, nutrient ratios, moisture level, pH, temperature and time. The success of the composting process in creating a healthy and nutrient-rich humus depends on the nutrients and elements within the materials being composted—namely carbon, nitrogen and phosphorous.

The optimal carbon-nitrogen ratio preventing nitrogen loss and proper composting is 30 to 1. To achieve this balance, different organic materials can be added (Modern Composting Technologies). In the case of the Skidmore stables, for example, the bedding for the horse stables affects the nutrient balance of any potential compost because some types of bedding have higher carbon contents than others. The type of bedding also affects how much moisture is retained, or not, in the composting process. Skidmore's three waste streams can be combined in the correct ratios in order to achieve the proper nutrient balance for the most rich and valuable compost possible. Tying in all three waste-producing infrastructures of Skidmore not only solves waste-disposal problems and reduces the campuses environmental impact, but also potentially produces a humus of increased monetary and ecological value.

Windrow Composting

Windrow composting is by far the most widely used method of composting worldwide. It can be applied on both a small scale, like on a small organic farm, or on a very large scale, to compost the yard waste from entire cities, as is done by the Saratoga Springs Department of Public Works. Windrows are an attractive composting method because they are very low cost in relation to the amount of material being composted and create a high-quality end product. Windrows require large amounts of space and are usually located outside; for this reason they are most suited to rural and suburban areas where ample space is available (UC Davis Guide to College-Wide Composting).

During windrow composting, organic material is piled in long, narrow rows between 4 feet and 12 feet tall. This shape allows for natural aeration and for the accumulation of sufficient amounts of heat within the piles, and also allows for easy access to the piles. Windrow systems can be roughly divided into passively aerated systems and actively aerated systems. In passively aerated systems, pipes or hoses are laid within the piles, allowing for increased air exchange. In actively aerated systems, the piles are periodically turned, usually with heavy machinery, to allow for aeration and proper mixing. Many different technologies are available for windrow composting, and are largely dependent on the scale of the operation (On-Farm Composting Handbook). For example, windrow turning can be accomplished with a front-end loader, or with a wide variety of specialized mechanical compost turners that can be attached to the side of a tractor or be self-propelled.

In-Vessel Composting

In-vessel composting refers to any type of composting process that takes place within an enclosed vessel. There are a variety of in-vessel composting methods that utilize a number of different forced aeration and mechanical turning techniques. The various in-vessel composting processes take place within some sort of container that requires an up-front capital cost either in construction or in the purchasing of a licensed product, such as the Earth Tub (UC Davis Guide to College-Wide Composting). With in-vessel composting, weather issues are eliminated, odors are contained and temperature is controlled more easily. While they do often require a higher level of knowledge and skill than windrow systems, in-vessel techniques are typically less labor intensive and generate compost comparatively faster. They also use significantly less land area than many conventional techniques.

In vessel systems can be as simple as bin composting, where materials are contained by walls, using space efficiently. During bin composting, compost is aerated by moving compost from one bin to the next in succession. Silos are bottom loading composting vessels, where air is blown from the bottom. A variety of more sophisticated in-vessel systems are offered by composting companies, which offer features such as automated aeration, temperature control, and electronic monitoring. Transportable containers are another interesting class of in-vessel systems. With transportable containers, organics are collected regularly at farms and other locations and collectively composted. Materials are composted partially in the container, then fully after they are transported to a central compost site.

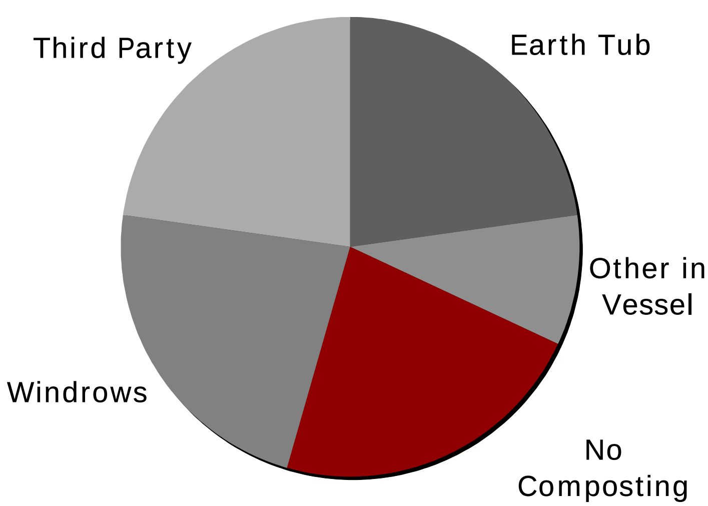
In vessel systems are becoming popular with many Colleges and Universities in the United States, particularly urban schools with limited space available for composting. Seven of Skidmore's peer and aspirant institutions use in-vessel composting systems. However, the enclosed nature of the in-vessel composting method either requires relatively small amounts of organic waste or a large capital investment, relative to the windrow method of composting.

COMPOSTING AT COLLEGE CAMPUSES

Composting is becoming a standard process at many Colleges and Universities throughout the country. According to *The College Sustainable Report Card 2010*, an evaluation of 332 colleges and universities in the United States and Canada, pre- and postconsumer food waste composting programs currently exist at 55 percent of schools. Among Skidmore College's peer and aspirant institutions, composting is even more prevalent, and at least 17 of 23, or 73.9% of institutions have adopted composting programs (See Figure 1).

Composting is a widely considered a low hanging fruit in regards to campus sustainability, and is a program that can both add to a school's green image while saving money in the long-term (UC Davis Guide to College-Wide Composting). In addition, it is a substantial addition to the green image of an institution, and can make an impact in the minds of prospective students who are choosing between colleges. This is reflected in College guidebooks and review sites, which increasingly include sustainability as a component of their reviews. For example, the Princeton Review's 2009 College Hopes & Worries Survey polled students, "If you had a way to compare colleges based on their commitment to environmental issues, how much would this contribute to your decision to apply to or attend a school?" In the Princeton Review study, 66% of 15,722 respondents said they would favor having such information, and 24% said it would "Strongly" or "Very Much" contribute to their assessment of a school. This information suggests that composting can serve an institution in a variety of ways, saving money while also contributing to an increasingly important “green image”.

Figure 1:
Composting at Peer and Aspirant Institutions



Middlebury College

Middlebury College, located in rural Vermont, is a private liberal arts college with approximately 2,350 undergraduate students and an endowment of 740 million dollars (June 2009). The College is well known for its focus on environmental sustainability, and was recognized for its sustainability by the *College Sustainability Report Card,* being one of only 26 schools to receive an A- rating in 2010. Its composting program is no exception, as the program was one of the first of its kind and began in 1993.

As part of an extensive recycling program, Middlebury College maintains a turned windrow composting system that processes up to 350 tons of food waste per year. A specially designed hook-lift truck picks up the food waste from several on-campus residential and dining areas twice a week and hauls the material to an off-campus site. Composting takes place on a piece of Middlebury property approximately one mile from its main campus. Although it is a rural location, the site is adjacent to a golf course and the compost operation is able to operate without causing odor or other problems.

At the site, a holding tank stores the materials until enough has been collected to create one complete windrow. The food waste is then mixed with wood chips, which are produced during landscaping projects and purchased from outside sources, and horse manure, purchased from a nearby farm, in the proportion of one part food waste to one part horse manure to three parts wood chips. A front-end loader is then used to align this mixture into windrows, long rows of compost that are about 10 feet wide, 10 feet tall and over 50 feet long. Windrows are constructed on a concrete pad, which creates a solid, dry surface for composting while preventing runoff to enter groundwater supplies. Any runoff funnels into one corner of the pad, where an artificial wetland consisting of cattails, rocks, and a berm purify and slow the movement of runoff. The windrows are turned with the loader routinely in order to achieve a healthy moisture, temperature and consistency, allowing these bio-active piles to get as hot as 160°F and hence killing any unwanted weed seeds and harmful bacteria. Although the windrows will compost quicker in warmer temperatures (about 3-4 months per windrow in the spring), Middlebury continues to compost throughout the year; snow that accumulates on the piles melts within days because of the high temperatures reached through biotic processes. After the initial windrow composting process is completed, the compost is screened by an outside contractor, removing unwanted materials (such as lost forks from the Dining Hall), and ensuring a high-quality compost with a small particle size that can be used on College athletic fields. After screening, the compost is allowed to mature for one year, a process that ensures the development of a stable and nutrient-rich humus.

For Middlebury, composting makes both economic and environmental sense, as it both diverts waste from landfills and saves money that helps underwrite the larger recycling program. In 2009, Middlebury saved $94,000 in landfill fees by composting 750 tons of material, but this is not the only way the college saves money by composting. The final product is used for nearly all of the campus's fertilization needs; it is used on the athletic fields, the organic community garden, throughout all landscaping projects, and is occasionally used as backfill during construction projects. Year after year, the grounds crew at Middlebury are happy to use all of the compost that is generated, cutting any spending on expensive chemical fertilizers that may have previously been used.

Melissa Beckwith, Manager of Bread Loaf Campus & Waste Management, says that composting is among one of the most financially sound investments that a College can make. During an interview, she was very enthusiastic about the system, stating that "composting pays for itself" while explaining the multitude of ways that Middlebury benefits from its composting system, both in terms of monetary savings and its environmental impact.

Smith College

Smith College, located in semi-urban Northampton, Massachusetts, is a private women's liberal arts college with approximately 2,600 students and an endowment of $1.1 Billion dollars (June 2009). Smith has taken numerous steps towards increasing environmental sustainability, including a 30% reduction in energy use, and was awarded an A- grade from Green Report Card in 2010, one of only 26 schools to receive the rating.

When two Smith College students did a sampling of waste at one of their campus dining facilities about five years ago, they found that one third of the material in the trash was compostable food waste. To bury waste in the local Northampton landfill, it costs Smith $75 per ton. Last year, Smith produced 150 tons of food waste, which would have cost them $175,000 in landfill fees had they not established a composting program. The College is able to compost through a mutually beneficial agreement with a local farmer, Peter Montague of Bridgemont Farm. The staff of the nine composting kitchens at Smith use 5-gallon buckets to collect their pre- and post-consumer food waste in 60-gallon totes, which are then collected by the college's waste truck and then transported to Bridgemont Farm. Every Tuesday and Friday, Smith delivers a truckload of food waste to the farm. In total, Montague welcomes 20 tons of food waste from Smith on a monthly basis, along with $400—less than a twentieth of what Smith would pay to send their food waste to the landfill. As this whole system is only a few years old, Montague is still perfecting his windrow system. He plans to eventually create enough soil with this new humus to fertilize his crops and to expand the area on which he grows food, and then sell the excess as a value-added product.

Apart from food waste, Smith College also generates large amounts of horse manure from their 36-horse stable and several truckloads worth of lawn-maintenance by-products. Currently, Smith sends a small amount of their horse manure to Montague to be composted, but in the coming months they plan on diverting all of it to Bridgemont Farm and thereby completely eliminate their current manure hauling expenses. The lawn-maintenance byproducts are piled and composted on campus, generating a mulch that the Smith Grounds crew uses in the campus greenhouse and grounds, although only as a supplement to the chemical fertilizer that the college purchases.

The organic waste disposal and composting program at Smith is a multi-faceted process that requires daily maintenance. Dining staff have to habitually transport 5-gallon buckets full of food waste and load toters, a driver has to transport the food waste to Montague's farm, lawn-maintenance byproducts are transported weekly to a site for composting and horse manure is also regularly collected and transported.

Despite this considerable amount of labor, however, the head of the Ground Crew at Smith, Bob Dumbkowski, asserts that the investment of time and money is worth it, saying that "if you look at what the investment is and what the return is, it's peanuts compared to what the college already spends [on waste disposal]". Apart from the huge savings in diverting waste from the landfill, Smith saves on fertilizer costs and, interestingly, plumbing fees. Several years ago, when the food waste was still simply flushed down the disposal, the College spent significant amounts of money on dealing with back-ups in the disposal and general disposal maintenance, not to mention the costs of water and power.

COMPOSTING AT SKIDMORE

Why a Windrow Composting System is Best for Skidmore:

Considering the relatively large amount of compost produced and the semi-rural location of Skidmore, we believe a windrow system would be the most appropriate and cost-effective on-campus composting system for the College. A windrow system would adequately process all of the institution's organic waste—horse manure, food waste and lawn maintenance by-products—providing the maximum benefit to the College for the least capital investment. In contrast, the Earth Tub, an in-vessel composting system, has a maximum daily capacity of 150 pounds, which is less than a tenth of Skidmore's total organic waste stream. Many other composting systems could be adopted if the three waste streams were to be composted separately. For example, it is likely that the food waste could be adequately composted with an in-vessel system, while horse manure could be sold to local farmers or be processed in an anaerobic digester. However, a windrow composting system will be the most logical and cost-effective if the College chooses to adopt a comprehensive composting system that incorporates all three organic waste streams. The following section outlines three different scenarios by which a windrow composting system could be adopted. The three scenarios are ranked from the cheapest and simplest possible windrow system to the deluxe, more expensive version. Their purpose is to detail all of the different options there are for implementing and maintaining a windrow composting system and can, by all means, be combined or reformed in the event that the Skidmore community does decide to compost its three waste streams. The scenarios also provide a template for a Skidmore composting action plan, meaning the College could choose to, at first, invest in the low-investment options and then, once the system is well established, adopt the higher-cost components of the more expensive scenarios.

Before outlining the scenarios, it is necessary to describe the features that will be common to all three, such as site location, transportation and labor processes.

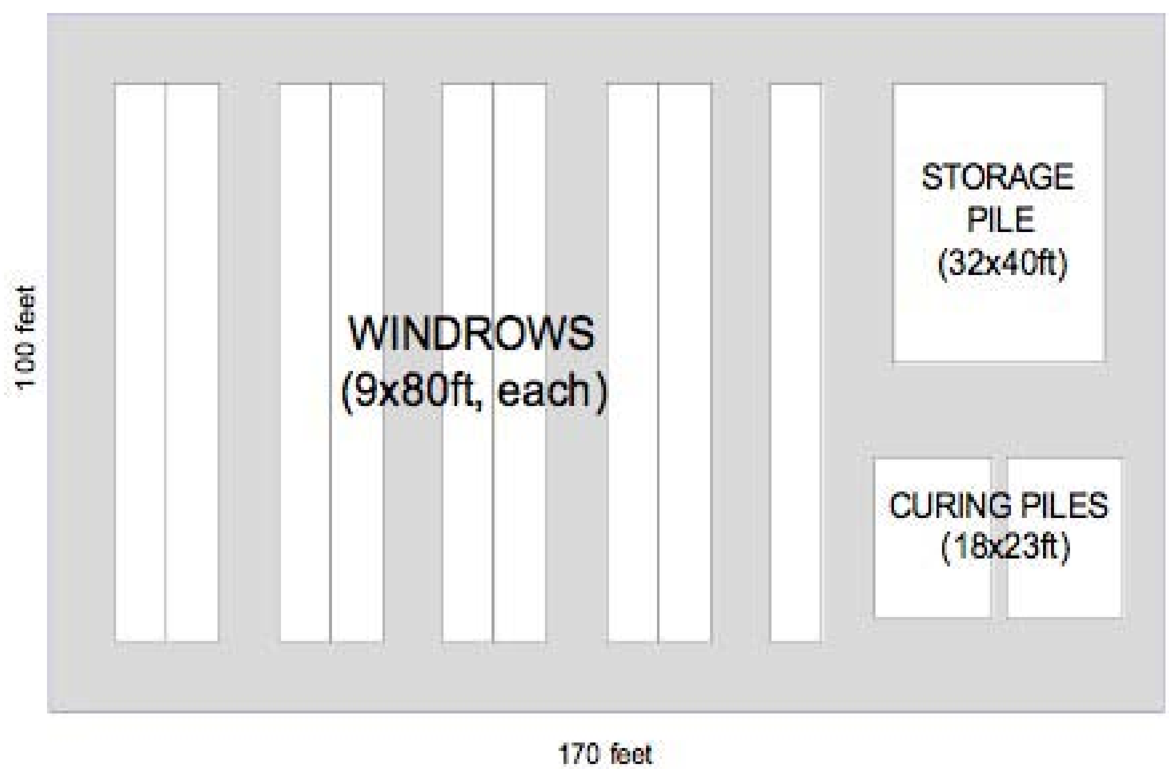
Composting Site Location:

After speaking with Paul Lundberg of Skidmore Facilities (3/24/10), we identified a parcel of land that is owned by the College and is located behind the Van Lennep Riding Center as an appropriate composting site (Appendix C). In keeping with New York Department of Environmental Conservation (NYDEC) regulations, the location is more than 200 feet from the nearest surface water body, potable water well, residence and place of business. Thus, the site minimizes potential environmental impacts of nutrient runoff, is sufficiently far away from other properties to prevent potential nuisance odor issues, and conveniently makes use of property that is already owned by the College. A storm water management plan must be implemented to minimize the effects of nutrient runoff from the compost site. This is an educational opportunity for the Skidmore community to research and implement an artificial wetland at the composting site. Whether it is a formal ecology class or as an independent study, a group of students would be able to learn through creating a useful bio-retention area that would mitigate any adverse environmental impact of the composting site. For example, Middlebury reports that they were able to build themselves an artificial wetland at little cost to the College.

Area Required:

The surface area that is required for the implementation and maintenance of a windrow composting system depends on the volume of the waste produced, the desired shape of the windrows and the space required to operate the equipment for turning the windrow. In addition to the space required for the windrows, the site also needs an area for the curing and storage of the finished compost—this is a smaller space since the volume of finished compost is about half the volume of the original waste material due to the loss of water and carbon (Dougherty 1999). In terms of composting at Skidmore the layout of the composting area is dependent on whether or not the College chooses to invest in a concrete pad (Scenario 3), crusher run (Scenario 2), or no impermeable surface at all (Scenario 1). Furthermore, the type of composting equipment that the college purchases will determine the height and shape of the windrow, curing and storage piles and, hence, the surface area required for the composting operation. For example, with the use of a front-end loader (Scenario 3), the windrows could be up to 12 feet tall and between 10-20 feet wide with at least a 20-foot space between the windows for operating the loader. On the other hand, with the Global Repair model #507 turner attachment that could fit on one of Skidmore's 50 horsepower tractors (Scenario 1), the windrows would be no more than 4 feet tall and 9 feet wide and could be formed in pairs with a small amount of space in-between and about 10 feet separating each pair. Below is a possible layout for this size of composting facility, with appropriate windrow, storage and curing pile dimensions:

Figure 1:
Example Layout for Composting Site; Scenario 1



Please see Appendix D for an example of how to determine the necessary dimensions of the surface area for a composting site for Scenario 1. The process for figuring out the lay out, as well as the crusher run/ concrete pad dimensions, for Scenarios 2 and 3 would be the same. In the example layout (again, see Appendix D), the overall square footage of the composting operation would be about 17,000 feet^2.

<u>Collection and Transport</u>:

Horse Manure (All Scenarios):

Horse stalls are mucked out each morning (approximately 7-11am) by stable staff. Horse manure will be transported to the compost site with a dump wagon and placed in a staging area.

Pre-consumer Food Waste (Scenario 1 & 2):

The dining hall staff will strategically place 5-gallon buckets for pre-consumer waste in kitchen preparation areas and at the six food stations. These buckets are easy to move, do not present an occupational hazard due to weight, can be cleaned in the facilities' dish machine without difficulty, and are free to the dining hall. When full, they will be emptied by kitchen staff into 60 gallon toters located on the loading dock. The compost manager will pick up the 60 gallon toters each morning, at approximately 8am, in a truck currently owned by Skidmore and drive them to the compost site. At the compost site, the compost manager will empty the toters of their contents in the staging area. He will drive the toters back to the dining hall and rinse them at the bin cleaning area, next to the loading dock.

Pre-consumer and Post Consumer Food Waste (Scenario 3)

In addition to the 5 gallon buckets to collect pre-consumer food waste, a pulper will replace the garbage disposals in the dining hall and allow for the composting of post-consumer waste. The pulper will pulp and dewater food waste, diverting food waste from the sewage system while reducing the amount of water and electricity used in the process. Both the pre-consumer and post-consumer food waste would be placed in an enclosed bin at the loading dock. Each morning, the compost manager would empty the bin by means of a truck with a hydraulic lifter, purchased by the composting program. The compost manager would then transport the waste to the compost site and compost it with the horse manure and yard waste.

Yard Waste (All Scenarios):

Yard waste is collected primarily in the Spring and Fall. 25 truck loads of yard waste are transported by Facilities to the composting site in the spring and about 50 in the fall. The yard waste will be piled, as it is now, and then added to the waste mix as necessary to achieve the most optimal composition for decomposition

<u>Composting Process</u>:

A compost manager will work 20 hours per week to ensure that the composting process is running smoothly. The duties will include transporting food waste from the Dining Hall to the site, creating new windrows, turning windrows, screening the composted material and managing the curing and storing processes.

Creating Windrows

If the windrows are made with a bucket loader, the windrows will be high, up to about 12 feet, with the base of the windrows ranging from 10 to 20 feet. After the horse manure, food waste and lawn waste are collected in the staging area, and mixed in the correct proportions, the compost manager will make a new section of windrow each day. To minimize odors and pests, horse manure and yard waste will be placed on the bottom and outside of the pile, while food waste is placed at the center. After the initial composting process takes place (approximately 1 week), the ingredients will be thoroughly mixed during turning.

Turning Windrows

The compost manager will turn each windrow as needed, approximately once per week. Windrows must be turned periodically to ensure proper moisture, temperature, and oxygen levels. How often the windrows should be turned or aerated depends on the oxygen, temperature, and moisture content of the windrows, and upon the current weather conditions. The windrows can be turned as often as anywhere between 2 days to 3 weeks. Because the decomposition rate is greatest at the beginning of the process, the frequency of turning decreases as the windrow ages. The composting system at Middlebury College suggests that, once a windrow system is established, the piles will be turned once per week. Through experience, the operator will gain a feel for the turning schedule and be able to ascertain when turning is needed.

Curing and Storage:

The curing and storage of the composted material takes place in an area adjacent to the windrows. In determining the area required for curing, it is important to note that the volume of finished compost will be 50% less than the volume of the raw materials (i.e. the initial input of the three waste streams). The curing process is when the second stage of decomposition occurs and the materials are humified. When temperatures drop in the windrow and all of the material has been decomposed and stabilized, with a moisture content of 40-50%, then the compost is ready for curing; this can take up to 3 months. One easy method to determine whether the compost is ready for curing is to thoroughly wet a small sample of the material, seal it in a plastic bag and then wait a week—if the compost in the plastic bag does not emit an odor after one week, then it is ready for curing. Curing provides maturity, with a slower rate of microbial activity than the initial composting process. The curing piles should be smaller than the windrows, no higher than 8 feet, to prevent anaerobic conditions at the center of the piles that cause phytotoxic compounds, pathogens and odors to develop. The curing piles should be aligned so their length runs parallel with the slope of the pad surface, allowing for adequate drainage and prevent wet, anaerobic conditions. If the curing piles are odorous or producing excessive heat, turning or a reduction in pile size may be necessary. The curing piles can be closely spaced, as there is no longer a need for regular turning (Dougherty 1999).

After the curing process, the material should be stored in a well-drained area in order to accommodate for the time between when the compost is ready and when it is used. The storage piles cannot be ignored and should be managed to avoid pathogen or weed contamination as well as fire hazards for more woody substances. The storage piles can be taller than the curing piles, however, especially if the material is wet, anaerobic decomposition can still be a threat, so it is recommended that the piles be no higher than 12 feet. A breathable, fleece cover can be used to protect storage piles, maintaining a favorable moisture content and deterring birds or other animals. Also, a few weeks prior to use of the compost, the storage piles should be restacked into smaller piles so that the final, humified compost can aerate naturally and any leftover phytotoxic compounds are dissipated. Open-sided buildings are another ideal place to store finished compost. New York DEC regulations stipulate that on-site product storage is limited to 24 months (Dougherty 1999).

Screening

After the composting process is completed and the material has been cured, screening is necessary to remove unwanted objects from the compost like plastic or metal and to ensure that particles have a small, uniform size. Prior to screening, water may need to be added to the compost to achieve a moisture content of 35-45% in order to prevent the creation of dust that can be a health hazard. A screener will be rented for two days annually to screen the year's compost.

For its yard waste composting operation, the City of Saratoga Springs rents a screener least once per year for a month at a time. There is a likely possibility that Skidmore could share the cost of renting the screener with the Saratoga Springs Department of Public Works (DPW). The DPW currently rents its screener from the company *Rock and Recycling* (a division of Vermeer) at a rate of $13,485 per month. Assuming the reasonable estimate that Skidmore would need two days to screen all of its yearly finished compost, and that a deal could be worked out with the DPW, we can say that it would cost the College around $900 per year to screen its compost.[iv]

Use of the Compost:

It is estimated that the three waste streams result in a total of 4521 cubic yards of organic waste a year. During composting, the volume of the material will decrease by approximately half, resulting in a total of 2260 cubic yards of finished compost per year.

The finished compost will be able to be used during landscaping of the Skidmore College campus, both as a fertilizer and as a soil amendment, in the place of mulch. Currently, 378 yards of dark landscaping mulch is used on campus per year, at the cost of $7986 (Erica Fuller, Personal Communication). Approximately 60 cubic yards of compost is used on the organic garden, at the cost of $1477. The school uses 175 lbs of tree and shrub fertilizer and 2500 lbs of grass fertilizer a year, for a total cost of $921.80 (Erica Fuller, Personal Communication). It is extremely likely that Skidmore compost would replace all mulch and compost used on campus. It will also be able to replace some amount of the fertilizer used, but the exact amount will be dependent on the characteristics of the finished compost, such as nutrient content and particle size. For example, Middlebury College compost has replaced all fertilizer use on campus, including on their varsity athletic fields, but this transition process took several years as the

[iv] This figure represents the amount Skidmore would pay to supplement the DPW's monthly rental fee for a screener and was derived by dividing $13,485 by 30 (days per month) and then multiplying by 2 (days).

composting program perfected its composting process (Melissa Beckwith, Personal Communication). A conservative estimate for fertilizer use is that compost, in the initial years of the program, would be able to provide 50% of tree and shrub fertilizer, and no grass fertilizer. Under this scenario, Skidmore College would use approximately 500 yards of finished compost on campus per year.

If 500 yards are used on campus, approximately 1760 cubic yards of excess compost will remain each year. This compost could be donated to the local community or could be sold to partially fund the composting program. Currently, Skidmore buys compost at the rate of 18.50/yard delivered, while the City of Saratoga Springs sells all of the compost it produces at a price of $125 dollars per seven yard truckload. If Skidmore College were to sell compost by the yard and not offer a delivery service, a reasonably low price would be $15/yard. Due to the high nitrogen content of Skidmore's organic waste, derived from the large amounts of horse manure and food waste, it is likely that this is an underestimate and that the compost could be sold at a higher rate. Nonetheless, at the price of $15/yard, and assuming no shortage of demand, the sale of compost would yield $26,407 per year.

Scenario 1: Lowest Investment

Composted material: Horse manure, pre-consumer food waste, and lawn waste.
Site Preparation: Material will be composted using a turner attachment on a cleared site. The advantage of this set up is that it requires minimal investment and can be reversed easily. The Sittler turner attachment model 507[v] will require the use of one of Skidmore's 50 horsepower tractors, either from the stables or facilities, approximately once per week. A potential disadvantage of this system is that the site could become muddy after rainfall, making it difficult to operate machinery. Without the use of a bucket loader, moving compost from one location to another will be done with a 50 horsepower tractor, which will be a time consuming process.
Financial Outcomes: Over a 10-year period, the net present value of the investment return is $84,515 not selling compost or $255,312 selling compost in 2010 dollars. The payback period would be 2 years and 1 year respectively.

Capital Investments:	**20,450**

[v] Sittler Windrow Turner Model #507. <http://www.globalrepair.ca/507turner.htm >

Turner attachment Sittler 507 for 50hp tractor	14,250
Site preparation	4,000
Storm-water management	1,500
Toters – 10	500
Compost testing materials	200
Annual Costs:	**20,900**
Compost Manager – 20 hours per week	20,000
Compost Screener – rent 2 days/year	900
Annual Savings:	**31,007**
Manure Disposal	20,065
Food Disposal	1390
Fertilizer Costs	9552

Scenario 2: Medium Investment

Composted Material: Horse manure, pre-consumer food waste, and lawn waste.
Site Preparation: Material will be composted on a crusher pad. The advantage of this system is that it provides a solid surface for composting and operation of the loader. Disadvantages are that the surface may only last for a certain number of years and requires the careful use of equipment to ensure the pad is not damaged. The purchase of a used front-end loader will aid in the composting process by serving as a windrow turner and as an efficient means of transporting compost from one location to another. It could also be used on campus for snow removal and small construction projects, serving many functions and saving in equipment rental costs.
Financial Outcomes: Over a 10-year period, the net present value of the investment return is $41,286 not selling compost or $313,725 selling compost in 2010 dollars. The payback period would be 7 years and 3 years respectively.

Capital Investments:	**78,700**
Front-end loader	60,000
Site preparation - Crusher run, prep and install 6"	16,500
Storm-water management	1,500
Toters – 10	500
Compost testing materials	200
Annual Costs	**20,900**
Compost Manager – 20 hours per week	20,000
Compost Screener – rent 2 days/year	900
Annual Savings	**32,272**
Manure Disposal	20,065
Food Disposal	1390
Fertilizer Costs	9552
Loader Rental Costs	1265

Scenario 3: Most Investment

Composted Material: Horse manure, pre-consumer food waste, post-consumer food waste, and lawn waste.

Site Preparation: In addition to the bucket loader described in Scenario 2, composting will take place on a steel reinforced concrete pad. This will provide a very solid and durable surface for composting. The disadvantages to this system are that it requires a very high capital investment and that is not easily reversible if the system needs adjustment or if another composting method proves more appropriate.

Food Waste: As described previously, the purchase of a pulper, holding tank and dump truck would allow for the inclusion of post consumer food waste.

Financial Outcomes: Over a 10-year period, the net present value of the investment return is a loss of $113,263 not selling compost or a gain of $154,346 selling compost in 2010 dollars. The payback period would be 18 years and 7 years respectively.

Capital Investments:	**252,200**
Front-end loader	60,000
Dump Truck with hydraulic lifter	60,000
Pulper	25,000 to 75,000 - 50,000
Site preparation -Steel Reinforced Concrete Pad 100’ x 200’	72,000
Storm-water management	1,500
Holding tank for post-consumer waste	5,000
Compost testing materials	200
Annual Costs	**20,900**
Compost Manager – 20 hours per week	20,000
Compost Screener – rent 2 days/year	900
Annual Savings:	**247,200**
Manure Disposal	20,065
Food Disposal	1390
Water Use – Dining Hall	800
Loader Rental Costs	1265
Fertilizer Costs	9552

Appendix A:

Composting Programs at Selected Peer and Aspirant Institutions

College	Type of Composting	Collection Methods/Labor	Amount Composted/ Type of waste	Costs/Funding	Money Saved	Operational Since	Where does it go?
Bowdoin College*	EarthTub™ compost system, 4 cedar-slatted bins at the organic garden, "Green Cone" at Green Residences	Student Employees	3 cubic yard capacity Organic pre-consumer food waste from the 3 dining facilities			2003	Bowdoin Organic Garden
Colby College*	Delivered organic waste to nearby Hawk Ridge composting facility in Unity, Maine	Dining Hall Employees. Accumulated in central Location, picked up by outside firm 1/month	Pre and Post Consumer food Waste, Yard Waste	$12,000	Per year: $2,000 - electrical costs for garbage disposals $10,000 - water use $10,500 - sewage fees.	2002, paper products since 2006	Hawk Ridge Composting Facility. College buys back compost for grounds.
Middlebury College*	Aerated Windrow System	Special truck empties toters/ brings food waste to compost site container. Use concrete pad. Add wood chips/ horse manure	Diverts 75% of college food waste. horse manure, wood chips, paper products	Awarded a state grant to expand its recycling program		1993	campus landscaping and vegetable production
Bard College	Compost pile in organic garden	Dining employees collect food waste in toters. BERD employee takes toters from to compost pile. Students collect from residence halls weekly	Pre and Post Consumer food Waste			2001 - dorm composting	Use 23 yards compost/ year for grounds
Bates College	Pre-consumer waste hauled by farmer, Wayne Ricker, who composts. Post-consumer waste goes to pig farm in Turner, ME.		84 percent of the food we don't use re-enters food cycle: to food bank, into compost or recycled or to pig farmer	Connecticut College alumna donated $25,000			used in the college's organic garden and donated to F.R.E.S.H. New London, a non-profit
Dickenson College	Composting at farm. commercial food grade Hobart pulper	Students collect, transport, and get food waste, Facilities turns makes compost recipe/ turns piles	700 pounds of food waste/day. Post/ pre consumer food waste. Yard waste.	Award: DEP Composting Infrastructure Grant for $93,000	Savings: $8,000 annually in tipping fees.	2005	180 acre College organic garden
Oberlin College	Farm receives waste from Dining Halls. Plan to purchase grinder/ pulper.	Farm picks up food scraps 3 times/ week, use to feed animals or is worm-composted	Compost pre consumer waste. Cafes compost coffee/ tea waste				George Jones Farm

Appendix B: Composting Regulations
New York State Department of Environmental Conservation

Compost facilities are considered solid waste management facilities in NYS DEC law and may fall into one of three categories, described below.

Exempt Facilities:

Types of Facilities:

Farms, residences, schools, industry, commercial establishments, correctional facilities, government facilities, state and county highway departments, and hospitals *that are composting materials generated at a location under the same ownership within a single region of the department* with the following conditions:

- Wastes do not include regulated medical wastes, septage biosolids, sewage sludge, or other sludges.
- DEC does not determine that the activities pose an adverse impact on public health, safety, or the environment.
- May accept outside materials including animal manure and associated bedding and no more than 3,000 $yards^3$ of yard waste. Additional brush and wood materials may be received for use as bulking agent in the composting process.

Are Required To:

- Operate without creating dust or odors that create a nuisance for neighbors.
- Process within 36 months, any material received at the facility.

Registered Facilities:

Types of Facilities:

- Accept from 3,000 to 10,000 $yards^3$/year of yard waste from external entities.
- Accept no more than 1,000 cubic yards per year of source-separated organic waste (such as food waste, soiled and unrecyclable paper - not biosolids, sludge, or septage).
- Accept food processing wastes from external entities.

Are Required To:

- Register with regional DEC office 30 days prior to operation by submitting the appropriate form, and may not begin operation until they receive validated copy of their registration from DEC.
- Operate a good, clean, well-managed facility that essentially follows the basic guidelines for a permitted facility, but no formal permit is required.
- Submit an annual report on the appropriate forms that will include the types of wastes received and annual volumes; where they came from and where they went; a description of any problems encountered; and any changes in operation.

Permitted Facilities:

Types of Facilities:

- Compost biosolids, sewage sludge, and septage.
- Compost yard waste and source-separated organic waste above the limits for registered facilities.
- Compost wastes from outside sources, other than the exempted manures with bedding, yard waste, source-separated organic wastes.

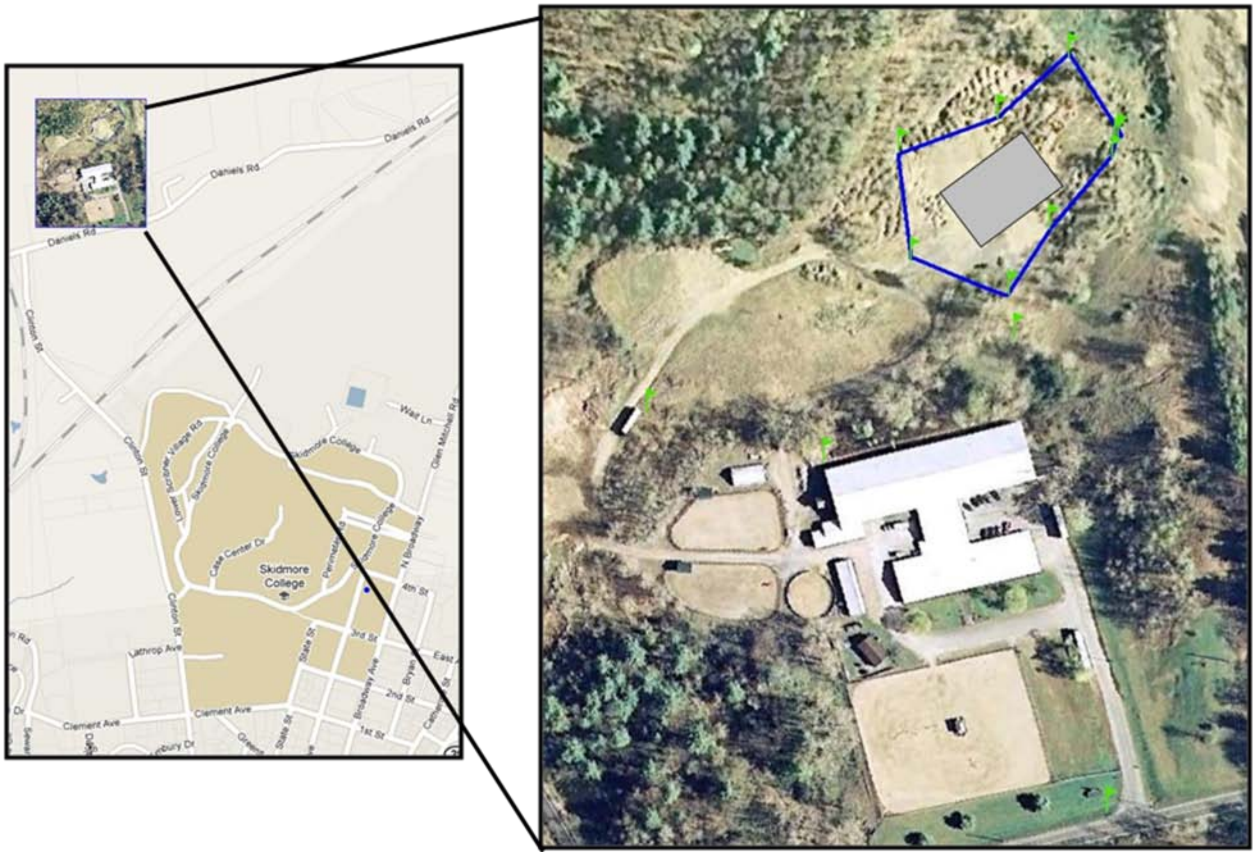
Are Required To:

- Submit an application to the appropriate regional DEC office. The application will include: a regional map; a vicinity map; a site plan; an engineering plan for the construction of the facility; an engineering plan for the composting process to be used; a description of the operational procedures to be used at the facility; a plan for maintaining, sampling, and analysis of the composting process, the ingredients, and the products; a product maturity and distribution plan; and a list of facility personnel and their responsibilites.
- Comply with State Environmental Quality Review Act which may include an Environmental Assessment form.
- Operate a good, clean, and well-managed facility with records and submit detailed annual reports.
- Minimize and contain water runoff and leachate from the facility.

This summary was adapted from a report by Cornell Cooperative Extension http://counties.cce.cornell.edu/washington/compost/Composting%20Regulations.doc.

You can find the complete regulation, "**6 NYCRR Part 360-5, Composting and Other Class A Organic Processing Facilities"** at http://www.dec.state.ny.us/website/dshm/redrecy/compost.htm

Appendix C: Proposed Composting Site
Behind the Van Lennep Riding Center



The proposed site is located behind the Van Lennep Riding Center, less than a mile from Skidmore's main campus. The site is marked by the blue polygon. This is the site where Skidmore Facilities currently dumps campus yard waste—they would not have to change this practice were a composting operation to be implemented here. The gray rectangle represents the approximate area that must be cleared for the actual composting operation (whether there is a crusher/ concrete pad or not). That is, all of the space within the blue polygon is not necessary for the composting operation, although this space is available.

Appendix D:

EXAMPLE LAYOUT

Scenario 1: Tractor with turner attachment

Determining the necessary dimensions for a composting site

<u>Assumptions:</u>

- Use of turner attachment with 50 horsepower tractor (Global Repair Model 507)
- The compost operation receives 12.4 cubic yards of organic waste per day
- Horse manure, food waste and yard waste are mixed in the correct proportions to create a favorable carbon-nitrogen ratio, of about 30 to 1.
- A given windrow length of 80 feet, with a composting site width of 100 feet, accounting for 10 feet space required for turner operation on either side of windrows
- The active composting period is 60 days (while in windrows)
- Windrows will shrink by a factor of .8 during active composting due to loss of carbon and H_2O, freeing space for more windrows
- <u>Windrows</u>: base= 9 feet, height= 4 feet, length= 80 feet (due to limitations of turner).
- A 50% shrinkage factor after active composting in the windrows
- Curing period of 30 days
- Storage period of 90 days

<u>Calculate</u>: Size of Windrows

- Volume of organic material handled per composting period: 12.4 yards^3 x 60 days= 744 yards^3. With shrinkage factor of .8, 744 yards^3 x .8 = **595 yards^3**
- Windrow volume[vi]: A= $^2/_3(9)(4)$= 24 ft^2. Volume= 24 ft^2 x 80 ft = 1920 ft^3 or **71 yards^3**
- Number of Windrows: 595 yards^3 ÷ 71 yards^3 (per windrow) = 8.4, or **9 windrows**
- With the use of a turner attachment, the windrows can be paired, with only a small amount of space in between every other windrow, and 10 feet between each pair.[vii]
- The total width required by the 9 windrows: 9 feet x 9 windrows (or 18 x 4 + 9) = 81 feet
- In addition, a space of 10 feet is required between each pair: 10 feet x 6 (spaces) = 60 feet
- 81 feet + 60 feet = **141 feet cleared site length necessary for windrows**

Thus, the total surface area required for the windrows is: **141 x 100 = 14,100 feet^2**

<u>Calculate</u>: Size of Curing Piles

- Curing pile volume: 12.4 yards^3 x 30 days x .5 shrinkage factor = **186 yards^3**
- Curing area: curing volume ÷ pile height; 186 yards^3 ÷ 2 yards= 93 yards^2 or **837 feet^2**
- Reasonable dimensions for curing pile: base= 18 feet, height= 6 feet, length= 46.5 feet

One curing pile with a base of 18 feet, a length of 46.5 feet and a height of 2 feet is necessary
Or, 2 piles with a length of 23.25 feet would be adequate, all other dimensions staying the same
Either way, the total surface area required for curing piles= **837 feet^2**

<u>Calculate</u>: Size of Storage Piles

- Storage pile volume: 12.4 yards^3 x 90 days x .5 shrinkage factor = 558 yards^3
- Storage area: 558 yards^3 ÷ 4 yards (12 feet) = 139.5 yards^2 or **1,255.5 feet^2**
- Reasonable dimensions for storage pile: base= 32 feet, height= 12 feet, length= 40 feet

One storage pile with a base of 32 feet, a length of 40 feet and a height of 12 feet is necessary.
Or, 2 piles with a length of 20 feet would be adequate, all other dimensions staying the same.
Either way, the total surface area required for storage piles= **1,255 feet^2**

Figure 2: Possible layout for this size of composting operation.
Total site area necessary: 14,100 ft^2 + 837 ft^2 + 1,255 ft^2 = **16, 193 feet ^{2}**
To account for extra space that may be necessary, we will round this number up to **17,000 feet^2**
Figure 2 (in the body of the text) shows a possible layout for this size of composting facility

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[vi] Using the formula for the area of a parabola, Area= (base) x (height)

[vii] This is because a windrow turner attachment has the capacity to turn one of two windrows while moving in one direction, and the corresponding windrow while moving in the opposite direction, on the other side of the pair.

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