GFS 0913

The Ecological Footprint of Composting and Incineration of Garden Waste in Denmark

An evaluation of the ecological benefits of incinerating garden waste in waste-to-energy facilities versus composting

An Interactive Qualifying Project submitted to the faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree of Bachelor of Science

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Abstract

This report assesses the environmental impacts of incineration with energy recovery and composting as two options for the disposal of garden waste in Denmark. By analyzing literature and speaking with experts in the field of waste management a recommendation was formed as to the most ecologically friendly plan for garden waste management. This study concludes that in most instances, incineration proves to be more environmentally friendly. Exceptions depend on the specific characteristics and operation of individual incineration plants.

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Authorship

This paper was a collaborative effort by all team members. All writing and research was contributed equally to by all authors.

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Executive Summary

Climate change and environmental consciousness are growing issues on the world stage, bringing forth both international accords and national legislation. This is especially true in industrialized nations where 'going green' has become main stream and a part of the culture. One such country is Denmark. With countless initiatives on clean energy, energy use reduction campaigns, advanced recycling, and environmental awareness Denmark has proven itself as a country dedicated to reducing its carbon footprint. Massive wind farms have almost become iconic to the relatively small nation of roughly 5 million people.

This climate of environmental activism has given rise to many organizations aimed at furthering the environmental charge. RenoSam is a collection of 38 waste management companies ranging from combined heat and power incineration plants to composting facilities. RenoSam's objectives are to further environmental awareness and education, encourage cooperation between waste management facilities, and inform policy makers of the most ecologically friendly waste management solutions available.

Though Denmark has a relatively small number of citizens it still needs to deal with the large amount of waste that they generate. One of the biggest fractions of this waste at over seven percent is garden waste. For a long time it has been assumed that the most environmentally friendly disposal option for garden waste was composting. With advances in technology, however, combined heat and power plants have emerged and efficiencies have greatly improved. This could imply that incineration is now an environmentally feasible disposal option for the hundreds of thousands of tonnes of garden waste generated every year. This possibility was also brought to light in a recent report by the United States Environmental Protection Agency (US EPA). In this report the US EPA concluded that in the United States incineration is actually more environmentally friendly than composting by roughly 0.01 metric tonnes of carbon equivalent per short ton of waste treated. Being as the United States does not currently have as advanced incineration plants as Denmark one might wonder if an analysis done in the Danish setting would reveal even greater emissions savings. These somewhat unexpected conclusions have led RenoSam to question whether or not the current composting process is really more environmentally friendly than incineration with energy recovery in Denmark.

The focus of this project is to help RenoSam better understand and evaluate the environmental benefits and costs of two existing garden waste disposal options by determining which method minimizes negative environmental impacts. It is the team's intent that RenoSam then uses this information to

better inform both themselves and Danish policy makers of the most environmentally friendly disposal option for garden waste taking into account the unique Danish situation. In so doing RenoSam will be fulfilling its aims of promoting high environmental standards for the treatment of waste as well as advancing education within the field of waste management.

Over the course of the project, the team realized its goals by completing the following objectives:

- Gathered information on the composting process
- Gathered information on the incineration process
- Analyzed this information and made a recommendation to RenoSam as to whether or not composting alone is the best garden waste disposal option.

The team gathered data by interviewing experts at two incineration and two composting facilities in and around Copenhagen. The facilities visited were suggested by RenoSam for their convenient location and their representation of the average facility in Denmark. Additionally, information was gathered from past studies, journals and reports on similar topics published in both English and Danish. RenoSam provided studies and benchmark numbers so that an accurate evaluation of the carbon dioxide emissions from each process could be calculated.

Due to the seven week time frame of this project the team made several defining assumptions in conducting the analysis of carbon dioxide emissions. When looking at the composting process, the first of these assumptions was that carbon storage in compost would be deemed negligible as carbon storage is only seen on a short term basis and the team was analyzing a sustainable long term process. The carbon in the compost is returned to the environment through its use in sustainable growth of biomass and therefore remains part of the cycle. Only carbon stored in humus formations for greater than 100 years was considered in this report. The second assumption made was that the benefit compost provided to the community was as a replacement for peat and fertilizer, as both of these have high rates of carbon emissions associated with them. As such the use of compost is seen to result in emissions savings.

In terms of the incineration process, the team used the academic understanding that the carbon released from the combustion of biogenic material is not included in the emissions accounting. This is because such carbon is part of the ecological cycle and is neither added nor subtracted from the total carbon in the environment. Finally, the team then assumed that energy captured by the incineration of garden waste would directly be replacing coal in terms of electricity generation and natural gas in terms of district heat generation. Both these fossil fuels are currently widely used in Denmark and as the Danes are trying to reduce the use of such energy sources these will be the first fuels to be phased out as replacement energy sources become available. If in the future these assumptions no longer hold true, such as the energy collected from garden waste no longer replacing energy from fossil fuels, then a new evaluation must be conducted.

The team also noted that not all garden waste is suitable for incineration. Some of it, mostly grass clippings and leaves, is too wet to be of benefit in the incineration process. These fractions also commonly contain dirt and small sand that can adversely affect the burners used in the incineration process. For these reasons some sorting is necessary. To a large extent, however, this sorting is already in effect at composting sites and collection points and where it is not the ability to implement it is easily available. Furthermore the benefits associated with fossil fuel savings when incinerating garden waste largely outweigh any additional sorting that is necessary for the waste's preparation for treatment.

As a result of this analysis the team determined that the usage of the energy generated in the incineration plants is the largest factor in determining the appropriate waste disposal method. Incineration plants that solely produce heat and are forced to cool off heat because it goes unused have no use for more fuel. In this situation it is more environmentally friendly for garden waste to continue to be composted, unless it can be saved for incineration at a later time. Most plants, however, produce both heat and electricity or produce and use their heat. These plants can utilize additional fuel and in turn prevent the combustion of fossil fuels. In such cases incineration is a vastly superior option for the disposal of garden waste.

Chapter 1: Introduction

Among the countries of the world few problems are of higher importance than that of climate change. International accords such as the Kyoto Protocol to the United Nations Framework Convention on Climate Change have shown a globally growing concern regarding greenhouse gas (GHG) emissions and their effects on the environment. On the forefront of the multilateral effort to further reduce GHG emissions is the small European country of Denmark with its population of less than 5.5 million (US CIA). Danes have long been known to be ecologically conscientious and are continuously looking for ways to reduce their carbon footprint. There are many areas that are of great importance when attempting to stem emissions, including improvements in power generation, transportation, and manufacturing. Another important but sometimes overlooked potential source for emissions reduction is through the management of waste created in everyone’s day to day lives.

RenoSam is a Danish association of waste management companies that strives to promote the highest possible environmental standards by encouraging co-operation between waste treatment facilities, spreading knowledge about waste management options, and advancing research in the field of waste management. Though Denmark is a relatively small country it still is forced to deal with a large amount of waste created by its populous. In 2005 the Danish waste stream consisted of 14,210,000 metric tonnes of garbage. Of this, one of the largest fractions was garden waste at over 563,000 tonnes (7%). Ensuring that garden waste is disposed of in the most effective possible method is thus of great importance to RenoSam, and to Denmark as a whole. Two options are currently available for the disposal of this waste; composting and incineration in waste to energy plants, yet their relative environmental implications were unclear.

Many studies have been done regarding the respective performance of composting and incineration of municipal solid waste. In order for these studies to be as thorough as possible they must take into account such considerations as transportation of the waste from the point of generation to collection points, transportation from collection points to the respective facility, the waste management process itself, the value of the end product, and location. One such report was published in Italy by Marchettini, Ridolfi, and Rustici (2007) that compared composting, incineration and land filling and concluded that composting had less environmental impact. The United States Environmental Protection Agency (EPA, 2004) also comprehensively analyzed emissions associated with multiple disposal techniques within the United States. This EPA report was supplemented by the waste reduction model (WaRM) calculator.

With such a calculator users, generally at a municipal level, can personalize the results by inputting figures on current waste disposal practices as well as proposed alternative practices and outputs the difference of emissions between the two in metric ton carbon equivalent (MTCE). The EPA concluded that specifically for garden waste the emissions differences between composting and incineration were small, with incineration having a slight advantage. Due to the completeness and exhaustive detail of the EPA report and the recommendation of RenoSam the WPI research team decided to use it as a primary reference in this study.

In a nation as environmentally concerned as Denmark waste to energy plants are constantly advancing. One way in which Danish technological advancement can be easily seen is in their highly advanced combined heat and power (CHP) plants which deliver a much greater efficiency then separate power generation and district heating. Such advances make it quite important to analyze the waste management situation on a regular basis. The unique Danish situation also creates a need for several distinctive considerations to be taken into account such as the feasibility of certain options and social importance of various waste management products.

This report filled in that gap of information by evaluating the environmental impact of both composting and incinerating garden waste through the existing infrastructure in Denmark. The evaluation took into account transportation from the home or collection point to the processes, machinery used in the processes, emissions from the actual processes, emission savings involved with the energy generation, and transportation of the compost to the end user. Additionally the report looked at the value of each end product, heat and electricity or compost, to the Danish society. An environmental cost-benefit analysis was performed for the existing composting system and was then compared to a cost-benefit analysis of a system in which the dry fraction of the garden waste is incinerated while the wet leafy matter is composted. This analysis found that incineration of garden waste would yield substantial carbon dioxide savings in most cases. With the information contained in this report RenoSam will be better able to inform both its members and Danish policy makers as to the most environmentally friendly garden waste disposal option.

Chapter 2: Background

The following chapter is dedicated to presenting basic material necessary in completing the objectives of this study. Though the final analysis was tailored to the Danish setting it was important to first understand the current American situation so that the team could better adapt information found in American studies and make more effective use of it. As such this chapter speaks to the social implications of waste in both Denmark and the United States as well as garden waste and its place in each society. Sections 2.3 and 2.4 then go on to detail the composting process and the waste to energy process respectively. Only through a thorough understanding of this material can a comprehensive recommendation as to the optimum waste management solution for garden waste in Denmark be formed.

2.1.Social Implications

The Merriam-Webster Dictionary defines Environmentalism as advocacy of the preservation, restoration, or improvement of the natural environment, especially the movement to control pollution. The potential positive environmental impact is the primary social implication of this study. Though eco-friendliness is a worldwide phenomenon, it is particularly noticeable in Denmark. As a world leader in renewable energy and pollution control Denmark is more sensitive to environmental impacts then most countries. Any project with potential environmental implications must take these issues very seriously and consider both official regulations and the weight of public opinion. Analyzing the development of environmentalism is a good way to gain an understanding of the current state of the issue.

2.1.1. United States Environmental Movement

As noted above, Environmentalism is in part the movement to control pollution. This movement is highly important when considering the social landscape of the United States. Five million American households contribute to environmental groups, which collectively receive over $350 million a year (Walls, 2008).

December 2, 1972 marked the birth of the United States Environmental Protection Agency. The EPA answered President Nixon’s call to:

- Establish and enforce environmental protection standards.
- Conduct environmental research.
- Provide assistance to others combating environmental pollution.

- Assist the CEQ (Council on Environmental Quality) in developing and recommending to the President new policies for environmental protection.

The president further illuminated the goals of the organization by stating the importance of viewing "the environment as a whole." Specifically, the presidents charge to William D. Ruckelshaus, the EPA's first Administrator, was to treat "air pollution, water pollution and solid wastes as different forms of a single problem." Upon taking office, the 38-year-old Assistant Attorney General became the governmental advocate of environmental progress and earned himself the nickname "Mr. Clean." Though the initial focus of the EPA was primarily on air pollution, the regulation of water and land pollution shortly followed (US Environmental Protection Agency, 2009).

The Resource Conservation and Recovery Act of 1976 was one of the first major pieces of legislation governing solid waste management. The primary focus of the act was the "cradle to grave" control of hazardous waste, but it also laid the framework for the treatment of non-hazardous wastes. The current EPA policy regarding the disposal of these Municipal Solid Wastes (MSW) is spelled out as a preferred order of treatment. The order is source reduction first, recycling and composting second, and disposal in landfills or waste combustors last. Source reduction refers to any change in the design, manufacture, purchase, or use of materials or products that reduces their amount or toxicity before they become MSW. Recycling and composting are practices that reuse resources to minimize the environmental impact of creating new products. Landfills and incinerators are seen as a last option because they have little or no reuse of materials (US Environmental Protection Agency, 2009).

The EPA now publishes a report entitled *Solid Waste Management and Greenhouse Gases* that specifically addresses the environmental implications of various waste disposal methods. The report explores the linkages between waste management, greenhouse gas (GHG) emissions, and energy and quantifies the emissions and energy use associated with source reducing, recycling, composting, incinerating, and land filling a variety of materials and mixed material waste streams. The most recent edition, published in 2006, contains information on all fractions of MSW and on all disposal methods. Of particular interest in this study is the information on the treatment of yard trimmings by composting and incineration. The data in the current edition of the report shows that incinerating yard waste results in a lower green house gas output than composting (US Environmental Protection Agency, 2007). Though the difference is small in magnitude, approximately 0.01 MTCE/Ton, it represents a 20% improvement over composting. Given the rising trend in environmentally friendly policies and other evidence in this report, considerations of switching from the composting of garden waste to incineration are both environmentally responsible and socially relevant.

2.1.2. Danish Environmental Protection

Danish environmental regulation began in the early seventies with the intent to combat Air Pollution. The current environmental administration in Denmark began in 1971 as the "Ministry of Pollution Combating", but the name was changed to the "Ministry of the Environment" in 1973. Environmental regulation came to the forefront after the passing of the Environmental Protection Act in 1974. The Environmental Protection Act and associated emissions guidelines have been updated many times since their original passing. In some of the more recent updates the direct regulatory measures have been supplemented with economic management tools and optional arrangements (Danish EPA, 2003). Early legislation focused primarily on limiting the emission of chemicals into the air, water, and soil. This focus was largely one of "pollution control". As the movement to preserve the natural world advanced, the focus shifted towards "environmental protection" (Sehested & Wulff, 2003).

An early example of the development of environmental protection is that of waste water treatment. Through the first half of the twentieth century waste water from private homes and industry was released into lakes, rivers, and oceans with no or very little treatment. This began to change in the seventies and eighties. In 1970 approximately 20% of waste water was treated through biological processes or biological-chemical means. By 1985 this figure increased to nearly 80% , and at the beginning of the twenty-first century this figure was well above 90% (Sehested & Wulff, 2003). During this time period, legislation was introduced to affect similarly positive changes in the emission levels of dust particles, sulfur dioxide, and nitrogen oxides from industrial facilities and power plants. According to the Chemical Law of 1980, any new chemicals have to be reviewed by environmental authorities before they can be used.

One issue that is always prevalent in environmental protection is that of waste management. In Denmark, waste management is a public sector task. This ensures that waste collection and treatment are handled properly. Danish waste management policy is administered by the Danish Environmental Protection Agency. Local and regional governments are in charge of executing this policy. Though Danes practice many types of waste disposal, a hierarchy is in place for disposal options. This hierarchy is very similar to its equivalent in the United States.

Recycling is highest in this ranking. Recycling, which includes composting, ensures maximum reuse of materials from waste. Items that cannot be recycled are incinerated with energy recovery. Incineration with energy recovery is similar to recycling in that it constitutes a reuse of old products, but it is not as environmentally friendly. Land filling is the lowest ranking option for waste. In this option there is no reuse, and there is a greater potential for atmospheric and ground water pollution. In Denmark, it is illegal to landfill waste that can be incinerated or recycled.

The waste management model used to apply this hierarchy is instrumental to the Danish system's success. Source separation is prevalent in Denmark. The separation of different types of waste is accepted and used extensively by both citizens and businesses. The organization of the system varies from municipality to municipality. Most large municipalities will manage their own waste, while smaller ones will often cooperate in inter-municipal waste management companies. Private companies are sometimes employed for collection and recycling. Hazardous waste is generally transported out of the municipality and managed on a national scale.

Administration and enforcement of these policies is carried out in many ways. Traditional methods including laws and regulations are used in conjunction with economic instruments ranging from taxes and charges to subsidies and agreements. Waste taxes are differentiated making it more expensive to landfill, cheaper to incinerate it, and making recycling tax deductible. A deposit system on beverage containers similar to that used in many US states is in place in Denmark to encourage proper recycling habits (Danish EPA, 1999).

The waste that is handled by this system comes from sources that can be grouped into five main categories: the construction sector, households, industry, commercial businesses, and service facilities like power plants and waste water treatment plants. Households account for approximately one fifth of the waste generation in Denmark. Of the household fraction of the waste, it is the garden waste fraction that is of interest in this study. Currently, nearly 100% of this fraction is composted (Danish EPA, 1999). Considering the environmentally responsible nature of Denmark's waste management policies in conjunction with the findings of the US EPA regarding the benefits of incineration over composting of garden waste, a study of a potential transition from composting to incineration of this fraction is called for.

Environmental protection is a concept that has been well developed in Denmark. Beginning with pollution control, proceeding to protection of the environment, the focus has now progressed to the concept of sustainable development. New products are being assessed with regards to the impact of their entire life cycle to more accurately determine and minimize their impact on the environment. Emphasis on reuse of materials has bolstered recycling and curbed the use of new raw materials. Environmental responsibility continues to be a large focus in Danish legislation, policy, and waste management.

2.1.3. RenoSam

RenoSam is an association of 36 Danish and 2 Faroese waste management companies that aims to promote high environmental standards within the field of waste management. A point of specific relevance is the membership of 13 Danish and 2 Faroese incinerators in RenoSam. The association further clarifies its aims with the following goals (RenoSam, 2004):

- To strengthen cooperation between waste management companies.
- To provide information on current activities, operational experience, and actual problems.
- To establish working relationships to other associations, institutions, companies, etc. which are engaged in related fields.
- To promote the mutual interests of its members to responsible authorities.
- To advance education and research in the waste management field.

Carrying out these goals is the job of the Political Association and Board. The political association consists of two representatives from the board of each member company. Its once-annual meetings are attended by the representatives as well as the general managers of each company. The council elects a board of seven members that meets whenever necessary to perform its duties, but at least four times each year. The board is assisted by two technical advisors who are chosen from the general managers of the member companies. The general managers meet regularly to exchange information and experiences (RenoSam, 2004).

RenoSam is a socially conscious organization that represents environmental and social interests in Denmark and the Faroe Islands.

2.2. Garden Waste

In order to better analyze the methods for disposal of garden waste it must first be made clear exactly what garden waste is as well as its place in both Danish and American waste management streams. To that end this section seeks to investigate the definition, current collection methods, and statistics for garden waste both in the United States and Denmark. This allowed for better informed comparisons to be made between the conditions in the United States and Denmark.

2.2.1. Garden Waste

The term “garden waste” refers to biodegradable waste consisting of items such as grass clippings, flower clippings, and small branches or other woody debris (Science Dictionary). In the United States garden waste is also commonly referred to as yard waste, or yard trimmings, which for this report will have the same meaning as garden waste. One of the many challenges facing garden waste management is its low density and subsequent high volume. This has a specifically high impact on transportation and storage. Other issues include its propensity towards having high moisture content, not only increasing the weight of the waste and decreasing its volume slightly, but also creating complications for some waste management techniques. High moisture content is very detrimental to incineration. This high moisture content is typically found in specific fractions of the garden waste stream, for example fresh grass clippings and old leaves. These and many more factors required careful consideration throughout this project.

2.2.2. Garden Waste in the United States

In 2007 the United States produced 254.1 million short tons (about 230.5 metric tonnes) of Municipal Solid Waste (US EPA, Municipal Solid Waste generation). Of this, 32.6 million short tons was garden waste as defined above, seen here as “yard trimmings” (US EPA, Municipal Solid Waste generation). Thus, without accounting for industrial waste generation garden waste in the United States constitutes twelve point eight percent of total waste. As seen in Figure 1 this fraction is topped only by paper, which commands nearly thirty three percent of the Municipal Solid Waste generated in the United States. Other fractions representing percentages comparable to garden waste include plastics and food scraps.

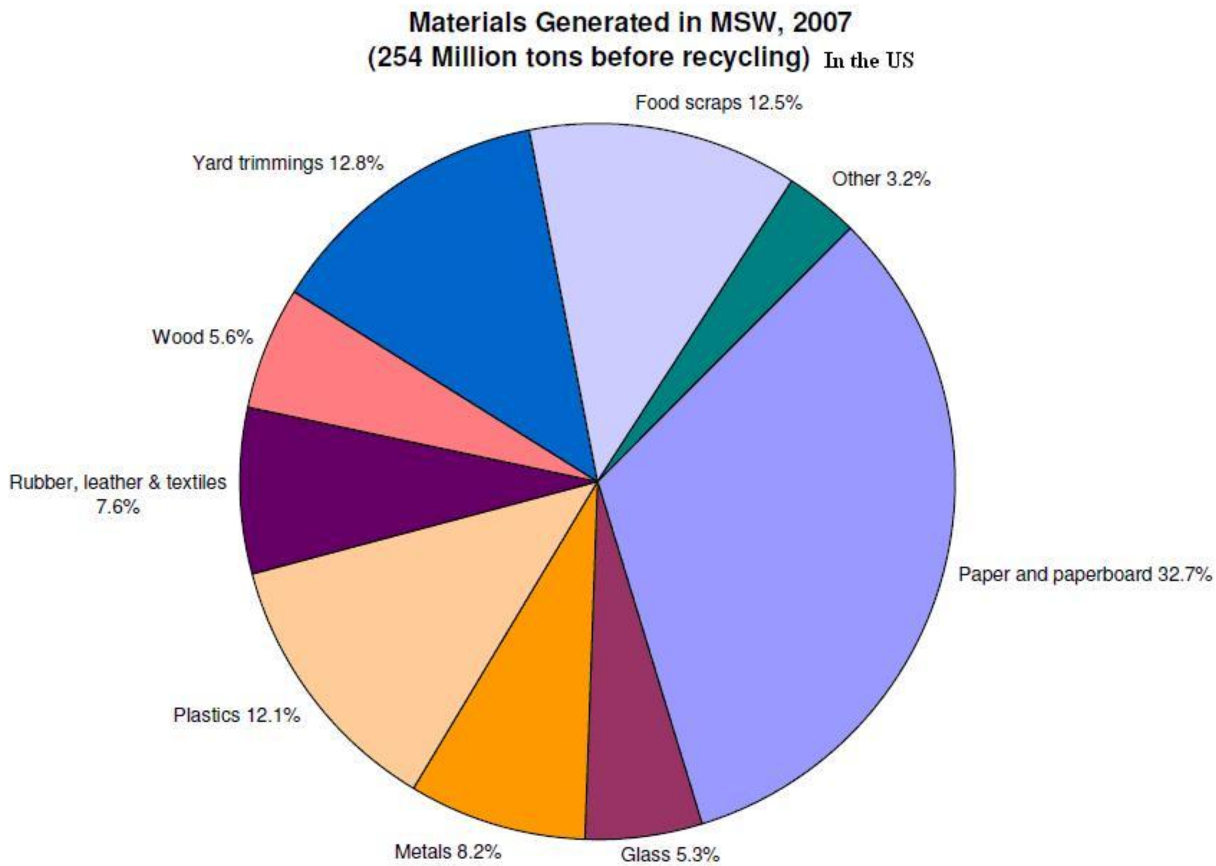

Figure 1: United States' Waste Breakdown in 2007 (US EPA 2008)

Waste management for garden waste in the United States varies from region to region. This can be partially accounted for by the fact that the waste-to-energy capacity of the United States varies greatly with location. The Northeast has roughly 850 tons/day incineration capacity per million persons, followed by the South with only 290 tons/day incineration capacity per million persons. From a national perspective however, 20.9 million tons of garden waste were composted in 2007. The remaining 11.7 million tons were "disposed of" through methods including incineration, but primarily not in waste to energy plants (US EPA, Municipal Solid Waste generation).

Garden waste in the United States is collected through one of two primary means as decided at the municipal level. The first of these is curb-side pickup in which residents remove the waste from their yard and place it in sorted fractions on the edge of the street during predetermined times. The waste is then either transported to Transfer Stations where it is sorted and prepared for long distance transport or in some cases is brought directly to the proper waste management site. The second model is to have residents (or their contracted gardeners) bring their garden waste to collection points where it is sorted and hauled to the proper location, again as directed by the local government. This second technique is currently in place in Paxton Massachusetts.

The rate of collection of garden waste in the United States is not constant throughout the year, particularly in the North East. During the autumn months of September, October, and November the majority of home owners commonly desire to remove the fallen leaves along with any fallen branches and other yard trimmings from their lawns and gardens. This constitutes a large spike in demand for garden waste disposal during this time. In order to cope with this high demand some cities, such as Worcester Massachusetts, offer special curb-side pickup days for garden waste.

2.2.3. Garden Waste in Denmark

In 2005 Danes produced more than 7,859,000 metric tonnes of waste, excluding imports, residue from coal-fired plants, and construction debris (Danish Environmental Protection Agency). This constitutes a raise of two percent from 2004. Of the almost 8 million tonnes 3,337,000 were produced by households; about forty-three percent of the total (Danish Environmental Protection Agency). Furthermore 563,000 tonnes of the household waste were classified as garden waste (Danish Environmental Protection Agency). This makes garden waste account for over seven percent of the total waste generation in Denmark, or approximately seventeen percent of household waste. Though this might not sound like a high percentage, it makes garden waste one of the highest fractions and thus a large concern for waste management companies. A breakdown of the Danish waste stream by percentage can be seen in Figure 2 where the yellow represents garden waste, the red and yellow together represent household waste, and the blue represents other waste fractions, again excluding imports, residue from coal fired plants, and construction debris.

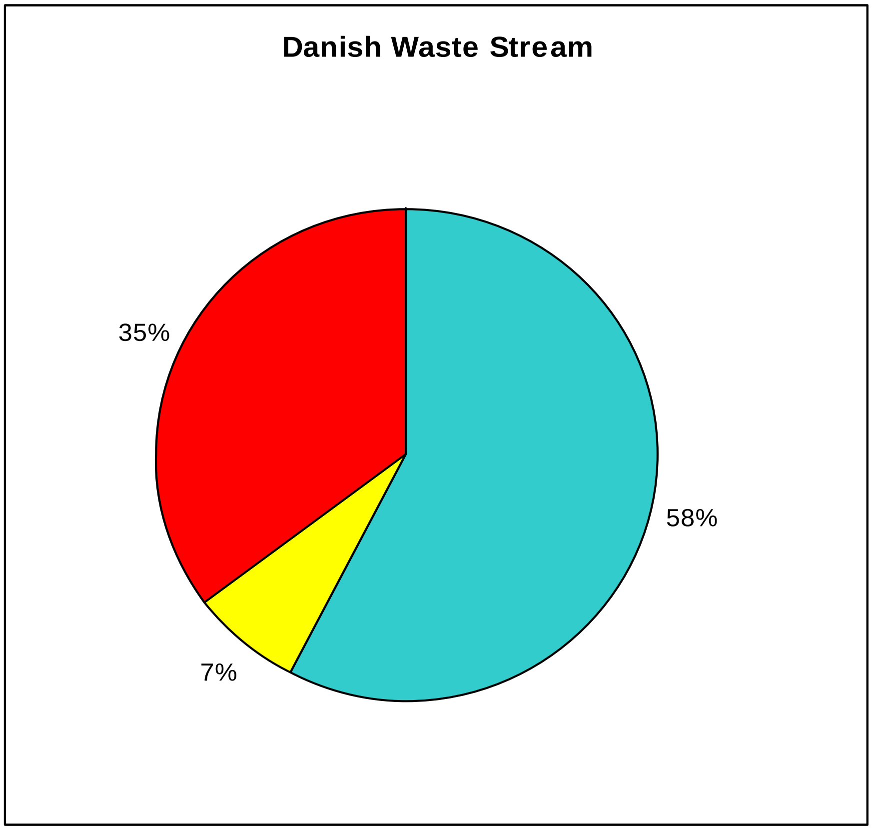

Figure 2: Danish Waste Stream

Based on the statistics above it can be calculated that every person in Denmark contributes approximately 104 kg of garden waste a year, and each household approximately 225 kg. This means that on average each of Denmark's 98 municipalities finds itself in need of collection and disposal for 5,750 tonnes of garden waste. Each municipality is able to choose its own methods, but many find it beneficial to pool their resources and work in conjunction to attain this goal. In order to aid in this attempt to create a more harmonious system many Danish waste management facilities have chosen to join RenoSam, whose goal is to unify the waste management community in an attempt to keep them better informed and insure maximum efficiency. A more in-depth look at RenoSam has been seen in section 2.1.3 of this report.

For many years garden waste in Denmark was primarily recycled through home composting. As more and more of this waste was collected by the municipalities it continued to be primarily composted, with approximately thirteen percent being put in landfills in 1994 (Danish Environmental Protection Agency). By 2005 following a ban on land filling any material that can be either recycled or incinerated over 99%

was being composted with the remaining one percent that was not suitable for composting being sent to landfills (Danish Environmental Protection Agency).

Over the eleven years between 1994 and 2005 the amount of garden waste in the Danish waste stream increased by nearly 95%. It is believed, however, that this figure does not properly represent an increase in waste production, but instead an increase of waste collection. This is thought to be the result of more easily accessible collection points and the institution of some waste pick up services allowing people to move from self composting to municipal collection. As the collection of waste has become much more efficient and accessible it is not likely that the amount of garden waste in Denmark will increase by another 95% in eleven years, but it is not unlikely for waste generation in 2010 to yield in excess of 600,000 tonnes of garden waste.

Garden waste in Denmark is primarily brought to its final destination through one of two routes; collection points or curbside pickup. Collection points are locations specially set up so that individuals can bring in their private waste (including garden waste) to be sorted and hauled to their respective destinations for disposal as decided by the municipality. In curbside pickup the individual separates their waste into predetermined fractions and places them beside the road. A collection truck then comes to the residence to retrieve certain fractions and bring them directly to their destination, again as decided by the municipality. This pickup can be done either by the municipality itself or can be privately contracted.

Danish garden waste disposal rates, much like in the United States, are not constant throughout the year. Unlike the in the United States however, in Denmark it is the spring months of April, May, and June that see the highest volume of garden waste. This is due to a cultural difference between the two countries, where Danes typically wait to remove the fallen leaves and branches from autumn until the spring. Thus when spring comes and Danes begin preparing their yards for summer municipalities see a great increase in the amount of garden waste in the waste stream. The timing of this project was thus quite advantageous as it provided the opportunity to examine the waste stream while garden waste was at its most prevalent.

2.3.Composting

Composting is a common method for dealing with biodegradable waste. It converts otherwise useless waste into a valuable commodity that is used frequently in farming, gardening, landscaping, and even to cap landfills. Being as it is a natural process it is often considered a more natural, greener alternative to other disposal options like land filling and incineration. Close analyses of the specific composting technologies applied in Denmark will allow us to test this hypothesis for validity. Properly considering the economic, environmental, and energy inputs and outputs of this system and others will allow for an accurate and relevant comparison to be drawn.

2.3.1. Process

Though composting processes vary according to the specific needs and goals of the system, there are some overarching traits that apply to composting in general. In its simplest form, composting can be described as the decomposition of organic matter into a humus-like product (Miller, 2005). More specifically, composting is the controlled biological decomposition of organic substrates carried out by successive microbial populations combining both mesophilic and thermophilic activities. This leads to the creation of a final product sufficiently stable for storage and application to agricultural field without adverse environmental effects (Elango, 2009). The resulting humus is a moist, nutrient rich soil that often is a dark brown color. Requirements for a successful composting process include aeration, constant temperature, stable moisture content, and an appropriate carbon to nitrogen ratio (Miller, 2005). Variations of these parameters define different composting processes.

Passive composting is the simplest form and is often seen in backyard composting operations. Many homeowners do little to regulate the composting process so these operations are often very similar to natural decomposition. In comparison to more active composting methods, passive composting is relatively slow and inefficient (Larney, 2000).

Active composting is carried out at high temperatures (Miller, 2005). In this case the parameters mentioned above, particularly temperature and carbon to nitrogen ratio, are rigorously controlled. At high temperatures aerobic bacteria thrive. Compared to anaerobic bacteria, aerobic bacteria accelerate the composting process and typically produce fewer odors (Smet, 1999). Active composting is often applied to large volumes of compost in municipal or commercial applications. One specific aspect of the process that is controlled in modern composting is that of aeration. Air is forced through the compost periodically. This stimulates the microorganisms which accelerates the composting process and increases temperatures (Smet, 1999).

2.3.2. Danish Composting Technology

Composting can be carried out in a number of ways, only some of which are practiced in Denmark. Within the category of active composting, different processes can be categorized as either in-vessel, or not. An in-vessel, or enclosed, system is isolated from the environment to ensure control of temperature, oxygen concentration, and odors (Danish EPA, 2003). For non-enclosed systems, there are two main categories. Static systems, usually referred to as Aerated static pile systems, are characterized by the stationary nature of the waste being composted, and aeration by blowers and air diffusers within the pile. These systems are typically used for uniform waste (i.e. sewage sludge) and are not suitable for the composting of garden waste. Dynamic systems that involve moving the waste pile during composting are typically used for garden waste.

In Denmark, there are two primary garden waste composting systems to consider: windrow composting as applied in the waste management industry and home composting carried out by citizens at their homes.

2.3.2.1. Windrow Composting

Windrow composting is the cheapest and most common method of composting in Denmark. The compostable material is stacked in long piles and allowed to heat itself through the natural biological processes taking place. Turning (mixing) the piles simultaneously aerates and cools them. This is accomplished using specially designed tractor like equipment that is capable of driving along a row of compost and turning the pile as it goes. Water can be added while turning to control the moisture content of the product. The figure below is a picture taken at the composting site in Roskilde.

Figure 3: Composting in Roskilde

2.3.2.2. Home Composting

According to Danish waste management policy, residents must give up their compost to the municipality for disposal unless they compost it at home. Composting carried out at home is very different from industrial composting. Home composting is typically carried out in small bins and is not as closely monitored in terms of moisture content, chemical composition, and temperature. For these reasons, the process is less efficient and results in much higher rates of GHG emissions, particularly methane (CH_4) emissions. Despite this, home composting is traditionally viewed as being environmentally friendly because no energy is expended transporting garden waste and compost to other locations. The analysis of home composting was deemed to be outside the scope of this project.

2.3.3. Danish Composting Usage

An important factor to consider when analyzing the Danish composting system is the overabundance of the end product. Compost can be put to many uses; its applications in Denmark are influenced heavily by the nature of Danish agriculture and economics. A study performed in 1999 noted that the largest fraction of compost is used in private gardens. The study found that 43% of the product was put to use in private gardens across Denmark. Other large fractions are usage to cover landfills (14%), green areas (13%), and agriculture (12%). The average sale price of this compost, which is made from garden waste and park waste, was at that time USD 60-65 per ton. The study also remarked that often the product is unable to be sold. More than one-third of all composting plants surveyed gave out free compost. (Petersen, 2001).

Transitioning garden waste disposal from composting to incineration will lead to the creation of less compost. This presents an issue because compost is a very necessary product, but is currently being over supplied in Denmark. When considering the ecological impacts of switching, taking into account what fraction of the waste supply would be redirected, as well as the resulting increases in compost demand and price, will be important considerations.

2.4. Incineration and Waste-to-Energy Technology

One of the ways that municipal solid waste (MSW) can be processed is by incineration. Simply burning the waste would emit CO_2 and other greenhouse gases into the atmosphere and would not provide a sustainable alternative to land filling or other discard methods; incineration with energy recovery however provides an alternative solution that in some cases may be more environmentally friendly than other options. Waste-to-energy (WTE) facilities have been built in many countries seeking renewable energy resources and sustainable waste management plans.

Many studies have conducted a life cycle assessment (LCA) to determine the ecological footprint of incineration of MSW. An LSA looks at the entire life span of a material, from the mining of it to the manufacturing it into a product to its disposal and determines the net cost of the material both economically and environmentally. In the case of yard waste there is no mining of the material and because biomaterial absorbs CO_2 while growing, the CO_2 emitted in the incineration of it is canceled out. Therefore, environmentally the important factors when determining the ecological footprint of the yard waste is the transportation and processing as well as CO_2 savings by displacing fossil fuel use. (United States EPA;) The ecological footprint is the amount of productive land required to provide the resources to sustain the process. An Italian study found that while a typical landfill has an ecological footprint of 1.5 hectares per ton of waste, sorting and incinerating waste has a footprint of -15 hectares per ton of waste. The study also compared the sorting of waste to the incineration of all MSW, the bulk incineration had an ecological footprint of -7.5 hectares per ton of waste. (Cherubini, Bargigili and Ulgiata) The negative footprints illustrate that this is a sustainable process as it does not require more resources than are provided and by offer ing an alternative to fossil fuels is actually working to counteract other non sustainable processes.

2.4.1. Combustion in the United States

The United States has approximately 65 WTE facilities which process about 22 million tons of MSW annually. (United States EPA;) This MSW includes everything from various metals, plastics, and rubber to food discards and yard trimmings. Most studies done in the United States on the environmental impact of combusting this waste ignore the carbon emissions from combustion of biomass such as yard waste. This means that the impact is calculated solely on the amount of carbon that was avoided by producing electricity in the WTE facility as opposed to a standard electricity generating facility, thus giving a net negative carbon emissions value for yard waste. Many studies also ignore the indirect carbon emissions from transportation of the waste. The United States EPA study found these emission values to be low compared to the values avoided, however the values were not deemed to be negligible. (United States EPA;) Waste-to-Energy facilities are not currently very efficient in the United States and present studies are limited because of this. As the efficiency of WTE facilities improve the amount of CO_2 avoided will increase.

2.4.2. Incineration in Denmark

As the Danish are very concerned with the environment, they have put a lot of effort into converting their energy resources away from coal and fossil fuels and into renewable resources. Their work with the European Union and their economic incentives for its citizens to move to a more sustainable lifestyle demonstrate their strong initiative to help prevent global climate change. In 1997 about 8% of primary energy was supplied by renewable resources and the goal is to reach 35% by 2030. (Manczyk and Leach) The incineration of biomass in combined heating and power plants is one of the largest contributors to the renewable energy supply. (Manczyk and Leach)

The Danish were pioneers in the field of waste to energy. In 1903 they built their first plant in Frederiksberg. (Kleis and Soren) In the 1960's the development of waste to energy incineration facilities took off. From 1965 to 1990 plants were built all over Denmark in rapid succession, however most of these plants produced heat only. In 1986 a small number of combined heating and power plants were built as demonstrations and the initiative was considered a success. (Kleis and Soren) In 1993 the Danish government established that "the application of waste for combined heat and power production must continue to take precedence over other kinds of fuel." (Kleis and Soren) In 2000 combined heat and power plants supplied 75% of the heating, additionally, 12% was provided by waste incineration plants. (Manczyk and Leach)

Because the waste is combusted in combined heating and power plants, the process has the potential for being much more efficient than in the United States. This then increases the amount of carbon emissions avoided by not using fossil fuels. The use of district heat was a major consideration in the analysis incineration in Denmark.

2.4.3. Process

The basic process of waste to energy plants is very similar to traditional coal or natural gas powered plants. In this case the waste is burned and the heat generated from the combustion is used to heat water and the steam is used to turn turbines, generating electricity, see Figure 4 below. In combined heating and power plants the spent steam is captured and used for heating (Knox), see Figure 5 below.

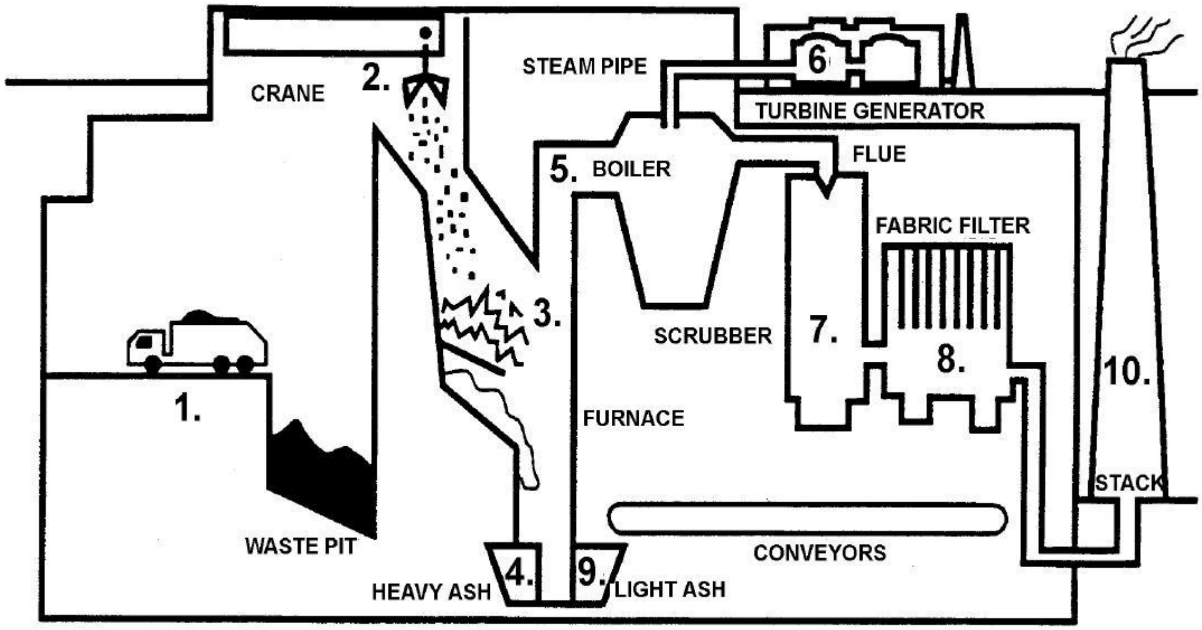

Figure 4: Typical US Waste-to-Energy Process Diagram (US EPA)

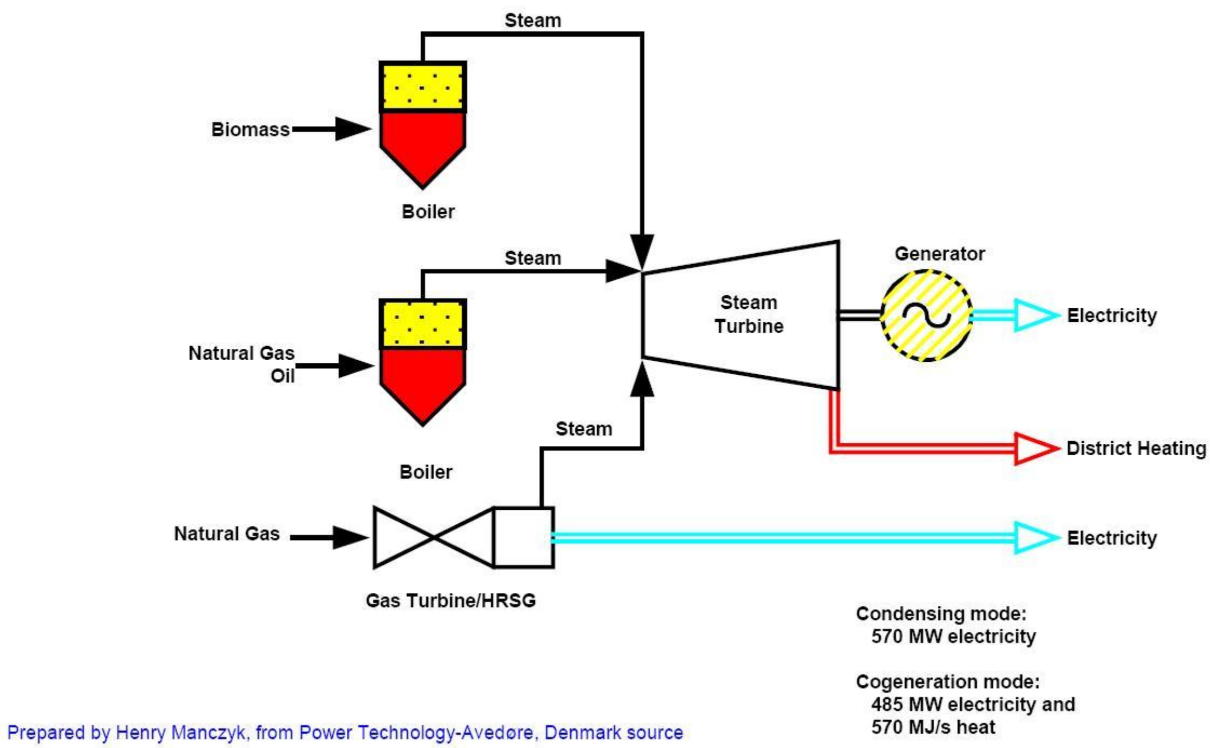

Figure 5: Typical CHP Diagram (Manczyk and Leach)

There are two types of waste incineration processes: mass burns and refuse-derived fuel (RDF). Mass burn incinerators generate electricity from the simple burning of MSW while an RDF facility burns waste that had been preprocessed in various degrees from shredding to material separation. (United States EPA;) Mass burn facilities are much less expensive to run as the only labor required is to dump the waste into an incinerator. However, this means the waste is bulky, has higher water content and is overall a less efficient fuel mix. Waste going to an RDF plant will undergo material recovery, where metals and other non combustible materials are pulled out beforehand, and will be shredded and the materials mixed in such as way as to give an optimal burn. (United States EPA;) While the combustion processes of an RDF facility is more efficient, the preprocessing increases labor cost and requires more material handling, which can minimize or diminish any extra efficiency that made be gained. Denmark utilizes only mass burn facilities and only data for this type will be gathered for this project.

Early incinerators had little to no management of emission quality and therefore earned a bad reputation with the public sector for their detrimental health effects. (Knox) New advances in technology have reduced the negative effects from combustion processes by adding stages to treat the ash and flue gas before releasing it into the environment. Older facilities have been updated to include and all new facilities are built with scrubbing, filtering, and other treatment of the flue gas to reduce gaseous emissions. It is important to note, however, that these treatments only reduce emissions, not eliminate them. (Knox)

2.5.Summary

Environmental concerns are some of the most pressing issues throughout the world today. In the United States, the Environmental Protection Agency creates guidelines and policies that ensure continuity and responsibility on a national scale. In Denmark, the Danish EPA performs a similar role, maintaining a high standard of environmental protection throughout the waste management system. A large fraction of solid waste from municipalities in both countries is that of garden waste. Consisting mostly of plant and grass clippings and leaves, garden waste's high moisture content and low density make it difficult to manage in conventional ways. It is traditionally handled separately from other solid wastes.

The waste management option currently applied to nearly all garden waste in Denmark is that of Composting. Garden waste is allowed to decay in a controlled manner over an extended period of time to form a rich soil suitable for fertilizing and landscaping. The alternative to this process that was considered is incineration with energy recovery. In this proposed scenario, waste is burned and the heat is used to generate electrical power and district heating. Though traditionally considered detrimental to the environment, new studies from the US EPA suggest that Incineration may be equally, or possibly more, environmentally responsible than composting. The environmentally conscious nature of Danish society, represented by the waste management association RenoSam, makes further study to determine the best option for the disposal of garden waste necessary.

Chapter 3: Methodology

The focus of this project is to help RenoSam to better understand and evaluate environmental benefits and costs of two existing garden waste disposal options by determining which method minimizes negative carbon dioxide emission. It is the team's intent that RenoSam then uses this information to better inform both themselves and Danish policy makers of the most environmentally friendly disposal option for garden waste taking into account the unique Danish situation. In so doing RenoSam will be fulfilling its aims of promoting high environmental standards for the treatment of waste as well as advancing education within the field of waste management.

Over the course of the project, the team realized its goals by completing the following objectives:

- Gathered information on the composting process
- Gathered information on the incineration process
- Created a Microsoft Excel spreadsheet calculation tool to help analyze the differences
- Made a recommendation to RenoSam as to whether or not composting alone is the best Garden Waste disposal option.

The overall work flow of the project can be seen in Figure 6.

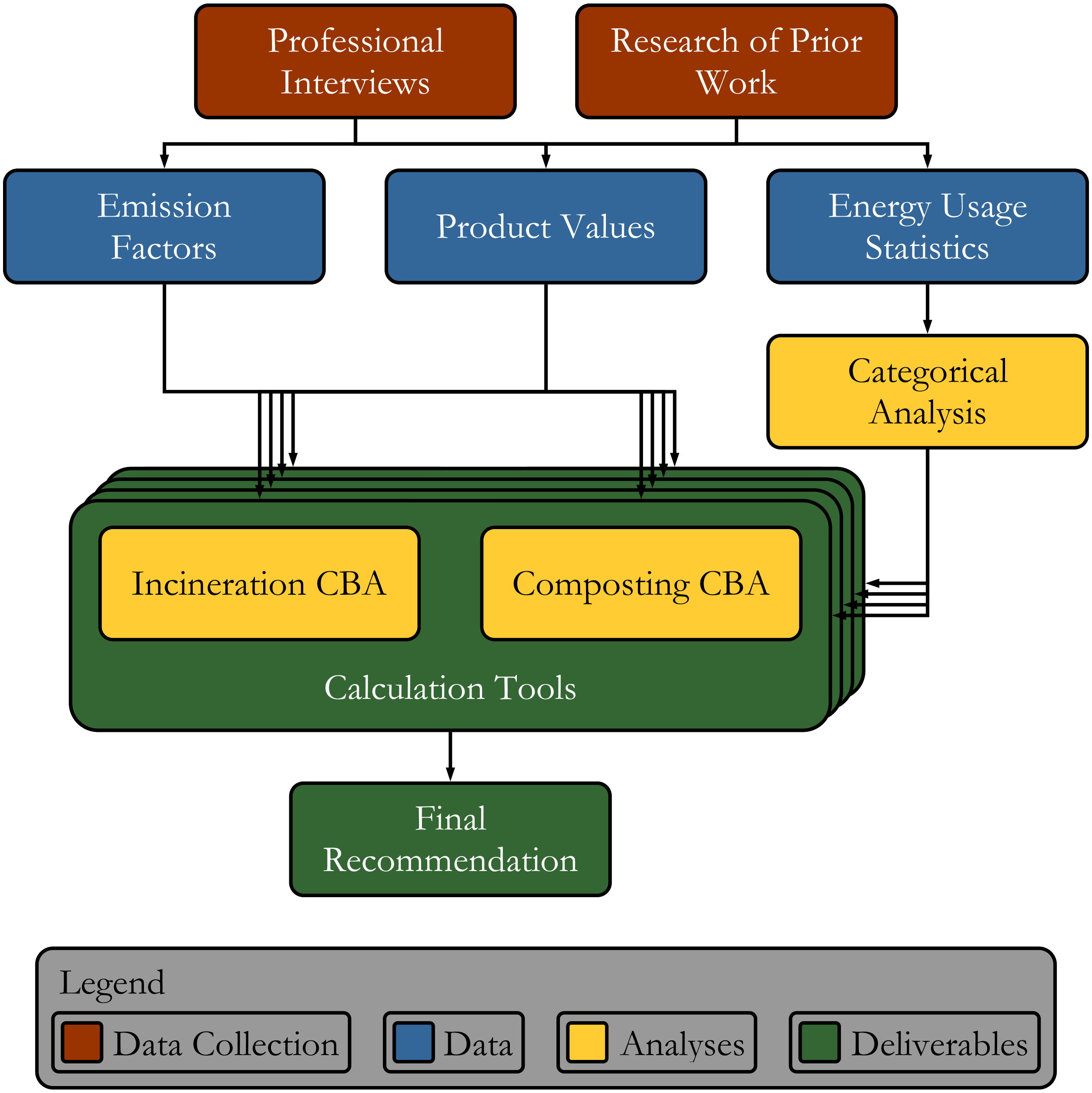

Figure 6: Project Flowchart

This project took place between March 23 and May 11, 2009. It culminated in a presentation at a daylong conference, 'Konference om Biomasse og Haveaffald' held by RenoSam for its members in Odense, Denmark, see Appendix H: RenoSam Conference Program. Also delivered to RenoSam was a copy of this report and a spreadsheet calculator used to allow a more focused case by case evaluation of the group's findings. In creating these deliverables to fulfill the objectives of this project the team executed the following steps:

- Analyzed the Current Waste Management System

- Assessed Carbon Emissions Associated With Garden Waste Delivery
- Performed a Cost-Benefit Analysis of the Current Composting Process
- Performed a Cost-Benefit Analysis of the Proposed Process
- Compared and Contrasted the Two Systems
- Made a Recommendation to RenoSam

3.1. Analyze Current Garden Waste Management System

The first step in this project was to assess the current waste management system to better understand the problem, as well as the possible solutions. The team first gathered information on regional differences in how municipalities currently collect, process, and dispose of their garden waste as well as differences in their ability to utilize the products of the garden waste disposal options. The team did this by visiting four composting and incineration sites suggested by RenoSam and interviewing the people overseeing the operations there, asking them about how the plant ran, what area it serviced, and how well the end product was utilized. These sites included waste collection facilities and waste to energy plants in Roskilde and Hørsholm, which are marked in yellow in Figure 7 as well as composting facilities and collection points in Hedehusene and København which are marked in red. Transcripts of these interviews can be found in Appendix C: Visit to KARA/Noveren Incineration Site through Appendix E: Visit to Nordforbrænding Waste Management Sites. In so doing the team was able to break down the requirements of municipalities so that a more specific recommendation could be made. The division was based off whether the incineration plant cooled down a significant amount of the heat produced and whether or not the plant also produced electricity.

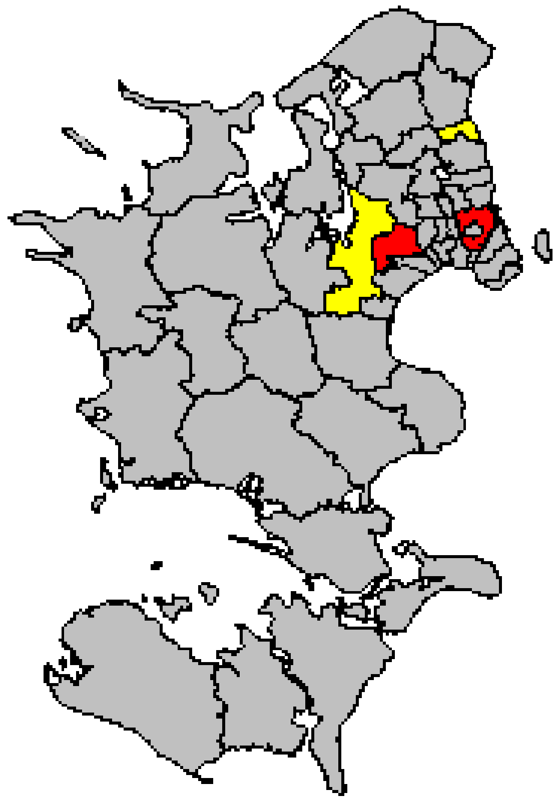

Figure 7: Sjælland Municipalities,

Visited Incineration Plants in Yellow and Composting Plants in Red

3.2. Assess Carbon Emissions Associated with Garden Waste Delivery

The transportation of garden waste before it arrives at a composting or incineration plant is an important issue in considering the environmental impacts of disposal because of garden wastes high volume. Transporting it in large trucks can consume a large amount of fuel producing non-negligible amounts of greenhouse gasses. For this reason, the team looked closely at each of the following parts of the materials path from homes and institutions to its end at a composting or incineration plant.

3.2.1. Transportation Prior to Sorting

Whether the waste is to be eventually composted or incinerated, the path it takes from its source to a central collection point is the same. This is true for waste being dropped off by the producer or collected from the side of the road by truck and then delivered. Being as this factor is the same in both the current system and the recommended system a comparison simply yields zero change. Furthermore this report seeks to illuminate possible benefits of incineration, composting, or a combined waste disposal method, and thus does not include the method of collection. For these reasons, this report did not analyze the transportation process before the collection site.

3.2.2. Sorting Process

For reasons such as density and moisture content, different types of garden waste are better suited to different disposal options. After speaking with incineration and composting experts at incineration and composting sites as well as people focused on similar issues in the academic community the team was able to determine which fractions of garden waste are best suited for which disposal option. These fractions were determined based on the water content of the particular item. Some sorting must therefore be done to separate out the fractions that are going to be composted from those that are going to be incinerated in the proposed system. By speaking with people involved in waste collection in the areas marked in yellow and red in Figure 7 above, and with Janus Kirkeby who is involved in the study of waste management at Videncenter for Affald, the team determined the environmental and other costs of this sorting process. Transcripts of these interviews can be seen in Appendix C: Visit to KARA/Noveren Incineration Site through Appendix E: Visit to Nordforbrænding Waste Management Sites.

When comparing the proposed and current flows of garden waste, the environmental costs of this sorting process were considered to be part of the proposed system. This is because the sorting goes above and beyond the sorting that is currently done prior to composting the material. The sorting is a necessary step in adding incineration to the garden waste management system.

3.2.3. Transportation after Sorting

Additionally, the material needs to be transported from the collection site to either the composting or incineration plant. To calculate the carbon emissions, it is necessary to determine the total amount and type of fuel used per tonnage of yard waste collected. To do this the team interviewed professionals currently involved in transporting garden waste. Due to the fact that all garden waste is currently composted professionals involved in the composting process were able to answer the garden waste transportation questions. Transcripts of these interviews can be seen in Appendix F: Visit to Solum Composting Facility and Appendix G: Visit to RGS 90. This number was then multiplied by the carbon emission factor for diesel; approximately 2.67 kg CO_2 per Liter burned (see Table 1 in Appendix A). The distances traveled from the collection point to the processing plant are different for composting and incineration in each municipality. The team asked experts at composting sites and incineration plants for an average distance that garden waste would have to be transported to be processed in certain service areas. Some of the service areas can be seen in Figure 8 below.

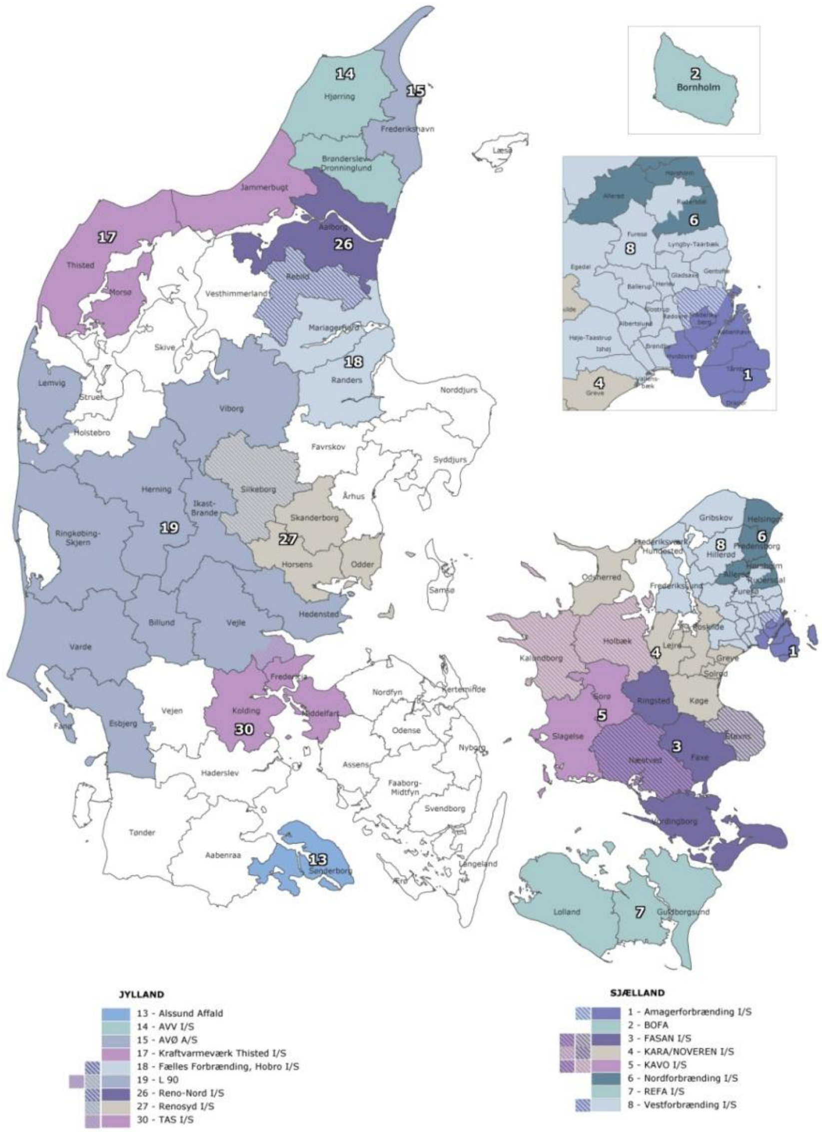

Figure 8: Service Areas in Denmark

3.3.Perform a Cost-Benefit Analysis of the Current Composting Process

When analyzing the current composting process the team looked at both the environmental costs and the benefits that the product provides to the community. Also considered was the capacity of the system for garden waste as well as the need for garden waste in the system. The environmental costs are seen in the transportation of the raw and processed material as well as in the machinery used to process it.

3.3.1. Assess Carbon Emissions Associated with Professional Composting

The carbon emissions associated with the composting process come mainly from moving the material around to aerate and to water it. This requires the use of heavy machinery. The team interviewed experts at two active composting sites (see Appendix E: Visit to Nordforbrænding Waste Management Sites through Appendix G: Visit to RGS 90), to determine the average amount of each type of fuel used in the composting process per metric tonne of yard waste and multiplied this amount by the carbon emission factor for the appropriate fuel, such as 2.67 kg CO_2 per Liter burned for diesel, from Table 1 in Appendix A. Any carbon dioxide emissions from the compost itself can be neglected because it comes from organic material. This is acceptable and standard practice in the academic community because it is assumed that the biomass absorbed CO_2 from the atmosphere during its lifespan, and only the amount absorbed is being released back into the atmosphere. This implies that the process is not introducing any new CO_2 into the environment.

Methane is another emission that is associated with the composting process. The United States EPA has concluded that any methane released by a properly regulated composting pile is negligible because there is such a small amount that when it contacts an oxygen rich environment it oxidizes to CO_2 which can be neglected for the reasons stated above (United States EPA;, 2004). After reviewing numerous other studies and talking with experts at the composting sites in Denmark (See Appendix F: Visit to Solum Composting Facility and Appendix G: Visit to RGS 90) the team decided to ignore the methane emissions as well because all the active composting sites were well regulated and the experts at them did not feel that methane was a problem.

3.3.2. Assess Carbon Emissions Associated with Home Composting

Unlike professional composting operations home composting does not require the use of large machinery. Furthermore it does not require the transportation of waste to collection points or a composting plant. It does however prove to be a significant source of methane because the process is not as well regulated as in the professional case. Primarily the lack of proper aeration and excessive moisture content allow the formation of methane pockets within the compost that slowly release into the atmosphere. While this is an important aspect to examine in an in depth evaluation of garden waste management, the team concluded that it was outside the scope of the current project.

3.3.3. Assess the Worth of Compost in Denmark

For the purpose of this project, the team measured the worth of compost solely by how much was needed to sustain farming areas, green areas such as soccer fields and golf courses, and small home gardens compared to the use of peat and fertilizer. The economic worth of the compost was deemed to be outside the scope of the project. In order to understand how much compost the country needed, the team traveled to and interviewed experts at composting sites, gathering data on the amount that they generally sold or gave away and who the end users tended to be. Compost that was sold or given to home owners, nurseries, or was used in the management of large fields such soccer fields and golf courses was given a higher value than compost that was used to cover landfills. In 2001, 14% of the compost was used to cover landfills; this can be seen as excess compost.

Compost has also been said to aid in the carbon storage capacity of soil on which it is used. However after research into this, including the US EPA analysis, the team decided to ignore any storage factors. Carbon storage is a time dependent effect and the impact diminishes over time. Because the team was looking at a long term, sustainable management solution, the carbon storage has a net value of zero. However, compost can also aid in the formation of humus, which traps carbon in the soil for upwards of 100 years, thus removing the carbon from the environment. The team examined the US EPA's report and used their findings on this topic.

Garden waste also plays an important role in maintaining the proper carbon/nitrogen ratios during the composting procedure. While interviewing the experts at the composting sites, the group gathered data as to how important the garden waste was, and what fractions of it the composting sites could do without. The team asked about the importance of branches in the compost in order to add structure and help aerate the large piles. Additionally the team inquired into whether or not the garden waste was mixed with other organic waste such as kitchen waste and sewage sludge. Background researched showed that garden waste may be vital when combined with other wastes as it contains much more carbon than both kitchen waste and sewage sludge. Transcripts of the interviews conducted at composting sites can be seen in Appendix F: Visit to Solum Composting Facility and Appendix G: Visit to RGS 90.

3.4. Perform a Cost-Benefit Analysis of the Proposed Incineration Process

Much like the analysis of the composting process, this investigation looked at both environmental cost and product value. It took into account the differences between plants defined in section 3.1. As in the composting process the incineration process requires the use of large machinery to transport and process the material, using fuel and emitting carbon. However the incineration process also reduces the need for other fuel sources for electricity and heat generation, thus the avoided carbon dioxide emissions from the burning of fossil fuels was taken into account.

3.4.1. Assess GHG Emissions Associated with the Incineration Process

Because this project only looked at the combustion of biomass and because it assumed the majority of the waste is from private homes and public parks the team ignored the CO_2 emissions from the combustion process for the same reasons as discussed in section 3.3.1. However moving the material around the facility requires the use of machinery which releases carbon dioxide. To account for this, the team determined the type of fuel used in the machinery and the amount burned per metric tonne of waste processed.

The team also determined if the plants use assisted burners to aid in the combustion of the garden waste. These burners add fuel to the process in order to obtain a more complete burn. The team determined the amount and type of fuel used in these burners and multiplied it by the appropriate carbon emission factors from Table 1 in Appendix A such as 57 kg CO_2 / GJ for natural gas. The gross carbon emissions were determined by summing the carbon emissions from the transportation, from the use of machinery and from the assisted burners.

3.4.2. Determined the GHG Savings from Using Alternative Fuel for Electricity Generation

The incineration of the yard waste in WTE facilities provides energy and heat that otherwise would have been provided by the combustion of other fuels such as coal or natural gas. In order to determine the amount of carbon emissions that was prevented by using this alternative fuel the team first calculated the amount of energy that was added to the system and then how much was used for electricity and how much for heating. The United States WTE industry declares that typical garden waste has an energy content of 2,800 Btu per pound (6.5 GJ per tonne) of garden waste combusted (United States EPA;). The efficiency of the WTE and CHP plants were then taken into consideration to determine the actual gigajoules provided to the heating and power systems. By multiplying that efficiency rate of the plant, a number less than one, by the energy content of the garden waste the team calculated the amount of energy that makes it into the utility system.

The team then determined how many kilograms of CO_2 would have been added had that amount of energy come from burning fossil fuels. Because this represents the carbon dioxide emissions saved due to the use of garden waste it was subtracted from the carbon dioxide emissions determined in section 3.4.1 to determine the net carbon emissions. See Equation 1 below where CE = CO_2 emissions.

Equation 1: Net Carbon Emissions for Waste-to-Energy

$$CE_{transportation} + CE_{process} - CE_{savings} = CE_{net}$$

3.4.3. Asses the Worth of Heat/Energy in Denmark

The Danish have long been leaders in moving forward with green and renewable energy. This is illustrated by the development of combined heating and power plants they have built that improve the efficiency of waste to energy. The plants also have adaptability in the fuel they can use, such as natural gas, straw, waste, biofuel pellets, and garden waste (Power-Technology, 2002). By burning garden waste less fossil fuels need to be burned, thus releasing fewer greenhouse gases into the atmosphere and reducing dependence on a nonrenewable resource.

In order to evaluate the value of garden waste as an energy source the team compared the gigajoules (GJ) generated per metric tonne (MT) of garden waste and the expected amount of garden waste to be incinerated to the total amount of gigajoules per metric tonne of non-renewable or less clean fuels. Equation 2 below illustrates the amount of energy that can be expected to result from incinerating garden waste.

Equation 2: Energy Provided from Garden Waste

$$\frac{GJ}{MT\ Garden\ Waste} \times Expected\ MTs\ of\ Garden\ Waste = Energy\ Provided_{Garden\ \ Waste}$$

Because coal still makes up a large percentage of the electricity generation, approximately 51% in 2007, it currently can be assumed that the electricity added to the system from the incineration of garden waste would be replacing this coal. However, it must be noted that in the future as Denmark moves away from coal and towards cleaner energy sources, such as wind, this assumption will not hold true. At that point and reevaluation would be required.

3.5. Compare and Contrast Composting and Incineration

After gathering the data described above, the team compared the calculated amount of carbon dioxide emitted by each of the two disposal methods for garden waste. The cost comparison was environmental in nature and both quantitative and qualitative. Product value was determined by environmental savings from each process and by qualitatively examining the need for each product in Denmark through expert interviews. First, the team compared carbon dioxide emissions per metric tonne of garden waste for each method. The team looked for the disposal solution that releases the least amount of carbon dioxide into the environment. These differences were calculated and visualized by using an excel spreadsheet developed similar to the US EPA WaRM calculator. These environmental costs were than weighed with the value and benefit of the product to the community. The value was seen in environmental savings in the production of heat and electricity in the case of incineration and in the avoided use of fertilizer and peat in the case of composting.

3.6.Recommend to RenoSam the Best Garden Waste Management Solution

After taking into account all of the considerations above the team made its recommendations to RenoSam. The team illustrated through calculations and graphs the environmental costs and benefits of each option. This was then compared with a qualitative analysis of the need of each product in Denmark. The team's analysis was then presented at a mini conference for members of RenoSam and the general public to further RenoSam's goal of advancing education in the waste field, see Appendix H: RenoSam Conference Program. Finally, the team made available to RenoSam a spreadsheet calculator that could be adapted to reanalyze this topic in the future should the assumptions that were made in this study no longer hold true.

Chapter 4: Results and Analysis

Currently in Denmark, the entire stream of garden waste travels through the composting process seen below in Figure 9. This process yields compost as a sole end product. In addition to the current process, the team also evaluated a proposed waste flow comprised of both incineration with energy recovery and composting. Below in Figure 10 is a flowchart representing the path garden waste would take in the proposed stream. At the end of each flowchart the end products of the processes can be seen; composting produces compost, while incineration produces power and heat.

4.1.Fractions of Garden Waste Suitable for Incineration

It was determined from research of similar studies, including one conducted by the US EPA, and through conversations with experts (see Appendix C: Visit to KARA/Noveren Incineration Site and Appendix E: Visit to Nordforbrænding Waste Management Sites) at the incineration sites that not all garden waste should be incinerated. Wet garden waste like leaves and grass clippings is inefficient to combust because the high moisture content makes it unfit for incineration. Some large roots that are too big to be composted are already being sent to incineration plants. Smaller branches and hedge clippings, the drier fractions of garden waste, are currently being composted but would incinerate well. They would become useful fuel for the waste to energy plants. According to the experts (see Appendix F: Visit to Solum Composting Facility), 30% of the current garden waste stream is suitable for incineration. The team was not able to define the wet and dry fractions in terms of specific moisture content beyond the fractional division mentioned above. Other research, including work being done by the Solum company, is looking into how efficiently specific fractions can be incinerated.

4.2.Environmental Costs of Transportation and Sorting

After speaking with employees at waste incineration and composting facility, as well as with others knowledgeable in the waste collection field it was concluded that further sorting of garden waste fractions could be carried out without incurring large additional environmental cost. For example, rather than labeling one bin at a collection site “Roots and Branches over 5 cm” and the other “Garden Waste”, they could simply be relabeled “Roots, Branches, and Woody Debris” and “Loose Leaves and Grass Clippings.” This is a small change from the current sorting scheme, and could be readily implemented. If this was not feasible, waste could be separated at the collection point with minimal additional effort due to the fact that some sorting is already in place.

4.3. The Current Composting Process

The team first analyzed the current composting process in Denmark. A depiction of this process can be seen in Figure 9 below. The value of compost to the community, home owners, the agricultural industry, and large sports facilities was compared to the environmental cost of the processes.

Figure 9: Current Garden Waste Flowchart

4.3.1. Product Environmental Value

Compost has several environmental values. It can be seen as a carbon storage material, and when used in gardens and in agriculture it can replace the use of fertilizer and peat. After much research the team decided not to include carbon dioxide storage in the calculations since this study is looking at a long term sustainable process. While compost stores carbon in the soil short term, the carbon is reused in ecological cycles. Thus over a long time period of several years, the amount of carbon stored in the soil has a net value of zero. This is due to the fact that the compost is being used for sustainable cultivation, which grows more biogenic material. This material is then returned to the waste stream. This reasoning is similar to the case in which carbon dioxide is released during the combustion of biogenic material. It is similarly not included in the calculations. If the analysis was for a non sustainable practice, such as handling the waste from cutting down a forest, this assumption would not hold true.

To consider compost as a replacement for peat and fertilizer, the team first determined how many tonnes of peat and of fertilizer could be replaced by a tonne of compost. Research into journals and past studies showed that 0.25 tonnes of peat and 0.10 tonnes of fertilizer could be assumed to be replaced by a tonne of garden waste. Using the carbon emission factors of 147 kg CO_2/tonne peat and 350 kg CO_2/tonne fertilizer with the generalization that a tonne of garden waste creates 0.35 tonnes of compost, the team calculated that a total 25.11 kg CO_2/tonne garden waste could be avoided, see Equation 3 and Equation 4 below.

Equation 3: CO2 Emission Savings from Avoided use of Peat

$$\frac{0.25\ Tonnes\ Peat}{Tonne\ Compost} \times \frac{147\ kg\ CO_2}{Tonne\ Peat} \times \frac{0.35\ Tonnes\ Compost}{Tonne\ Garden\ Waste} = \frac{12.86\ kg\ CO_2}{Tonne\ Garden\ Waste}$$

Equation 4: CO2 Emission Savings from Avoided use of Fertilizer

$$\frac{0.1\ Tonnes\ Peat}{Tonne\ Compost} \times \frac{350\ kg\ CO_2}{Tonne\ Peat} \times \frac{0.35\ Tonnes\ Compost}{Tonne\ Garden\ Waste} = \frac{12.25\ kg\ CO_2}{Tonne\ Garden\ Waste}$$

When evaluating these results it is important to note several different scenarios. These calculations assume that homeowners who are currently using compost would switch to peat and or fertilizer if they compost was no longer available. However, some homeowners are currently using fertilizer in addition to compost. If compost was not available then these homeowners would have multiple options. They could choose not to add anything to their gardens, but to grow with the soil as is. If they were previously using fertilizer then might continue to use the same amount with or without the added compost. If they were using compost they might switch to peat. It is beyond the scope of this project to determine the behavioral changes of homeowners. Therefore the team has decided to consider the specific case in which home owners that are currently using compost would switch to a combination of peat and fertilizer.

As biomass decomposes the carbon that it contains is released into the atmosphere as biogenic CO_2. During this decomposition process the carbon forms intermediate compounds that have different characteristics depending on a number of variables, including the parent compound. In the case of garden waste compost this decomposition of carbon compounds results in stable carbon compounds with a ‘long’ half life. This carbon is considered to be added to the passive carbon pool of the soil, and therefore is removed from the environment. This is known as humus formation. Though this effect is not permanent, the team decided to include any carbon that is stored in stable compounds for more than 100 years as savings resulting from the composting process. To this end the team used the US EPA’s bounding analysis (US EPA, 2004) of humus formation to calculate an emissions savings of 121 kg CO_2 per tonne of garden waste.

4.3.2. Environmental Costs

Transportation of both raw and processed material as well as the actual processing of the material requires the use of fuel. This emits carbon dioxide, which is an environmental cost. The team gathered data on the amount of fuel used to process one tonne of garden waste by asking the sites visited and Janus Kirkeby. The team learned from Kirkeby's notes that 12.5 Liters of diesel per tonne of biowaste processed can be expected to be used. The team decided to use Kirkeby's value for garden waste because the processes being considered are similar. Multiplying this value by 2.67 kg CO_2/L diesel (from Table 1 in Appendix A: Calculations and Parameters Used) yields a value of 33.38 kg CO_2/tonne garden waste, as seen in Equation 5 below.

Equation 5: CO2 Emissions from Composting Process

$$\frac{12.5\ Liters\ Diesel}{Tonne\ Garden\ Waste} \times \frac{2.67\ kg\ CO_2}{Liter\ Diesel} = \frac{33.38\ kg\ CO2}{Tonne\ Garden\ Waste}$$

For transportation the team used a liberal estimate in which the garden waste is transported 30 km from the collection point to the composting site. In most cases this is a greater distance than can be expected, but the emissions from transportation were very small compared to other aspects. They represent less than one third of the emissions from the process of composting and less than one fiftieth of the emissions saved in incineration. For this reason, changes in the distance traveled are negligible to the overall analysis. The team verified this by conducting a sensitivity analysis using larger and smaller values. The 30 km value was then multiplied by an average fuel economy of 0.3 L/km for a standard diesel truck. The team used the assumption that the average delivery truck can carry eight tonnes, and that the same 2.67 kg CO_2/L diesel emission factor as earlier. Using dimensional analysis as shown below in Equation 6, the team calculated that 6.01 kg CO_2/Tonne Garden Waste is released.

Equation 6: CO2 Emissions from Transportation to Composting Site

$$30\ km \times \frac{0.3\ L}{km} \times \frac{2.67\ kg\ CO_2}{Liter\ Diesel} \frac{2.67\ kg\ CO2}{Liter\ Diesel} \times \frac{1\ Truck}{8\ Tonnes\ Garden\ Waste} \times 2\ for\ Return\ Trip$$
$$= \frac{6.0100\ kg\ CO2}{Tonne\ Garden\ Waste}$$

Additionally, the compost has to then be transported to the end user. This delivery has many possible routes. Compost can first be bagged and sold in stores, picked up on site by private cars, or delivered in the case of professional uses such as golf courses and soccer fields. Due to the complexity of this and due to the results of the team's sensitivity analysis of the pre treatment transportation the team decided to double the emissions from transport to the composting site in order to take into account the delivery of the compost.

The net savings resulting from composting garden waste is -100.73 kg CO_2 per tonne of garden waste, see Equation 7 below.

Equation 7: Net Composting Emissions

$$\frac{-12.86\ kg\ CO_2}{Tonne\ Garden\ Waste} from\ Peat\ Avoidence + \frac{-12.25\ kg\ CO_2}{Tonne\ Garden\ Waste} from\ Fertilizer\ Avoidence + \frac{-121.0\ kg\ CO_2}{Tonne\ Garden\ Waste} from\ Humus\ Formation + \frac{33.38\ kg\ CO_2}{Tonne\ Garden\ Waste} from\ Processing + \frac{12.02\ kg\ CO_2}{Tonne\ Garden\ Waste} from\ Transportation = \frac{-100.73\ kg\ CO_2}{Tonne\ Garden\ Waste} Emitted$$

4.4.Incinerating the Dry Fractions of Garden Waste

For the reasons stated earlier in this report, the team made the decision that only dry fractions of garden waste, such as branches, should be incinerated. The outline of this process can be seen in Figure 10 below. Using this process as a guideline the team analyzed the incineration side, weighing the environmental costs against the savings the incineration of garden waste provides.

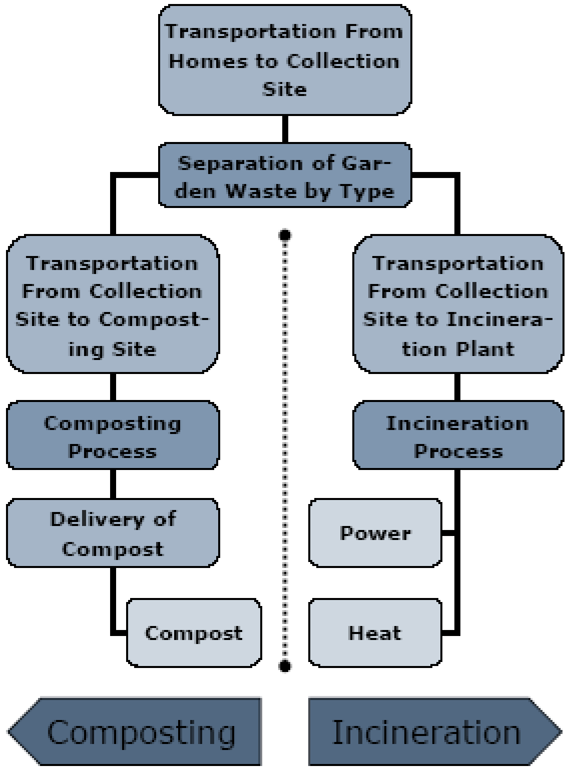

Figure 10: Proposed Garden Waste Material Flowchart

4.4.1. Product Environmental Value

The ability to produce heat from combined heating and power plants is a great boost to the value of the incineration process. Capturing used steam and putting it to use in district heating is both economically and environmentally advantageous. In order to calculate how much carbon dioxide is 'saved' by the burning of garden waste the team first determined how much energy would be provided to the system. The United States EPA uses a value of 2,800 Btu (6.5 GJ) per tonne of garden waste. The team used this number after research into other studies yielded similar numbers (Cherubini, Bargigili, & Ulgiata, 2008) and (Energy Information Administration, 2007). The team next looked into the efficiencies of the incineration plants in Denmark. The team used data provided by RenoSam to determine the average efficiency of the plants to be 84.5%. While the plants varied somewhat in efficiency from approximately 70% to 94%, see Figure 11 below, the range of variation was deemed too small to make a large difference in the calculations and thus national the average, seen in Figure 12, was used, see Figure 12.

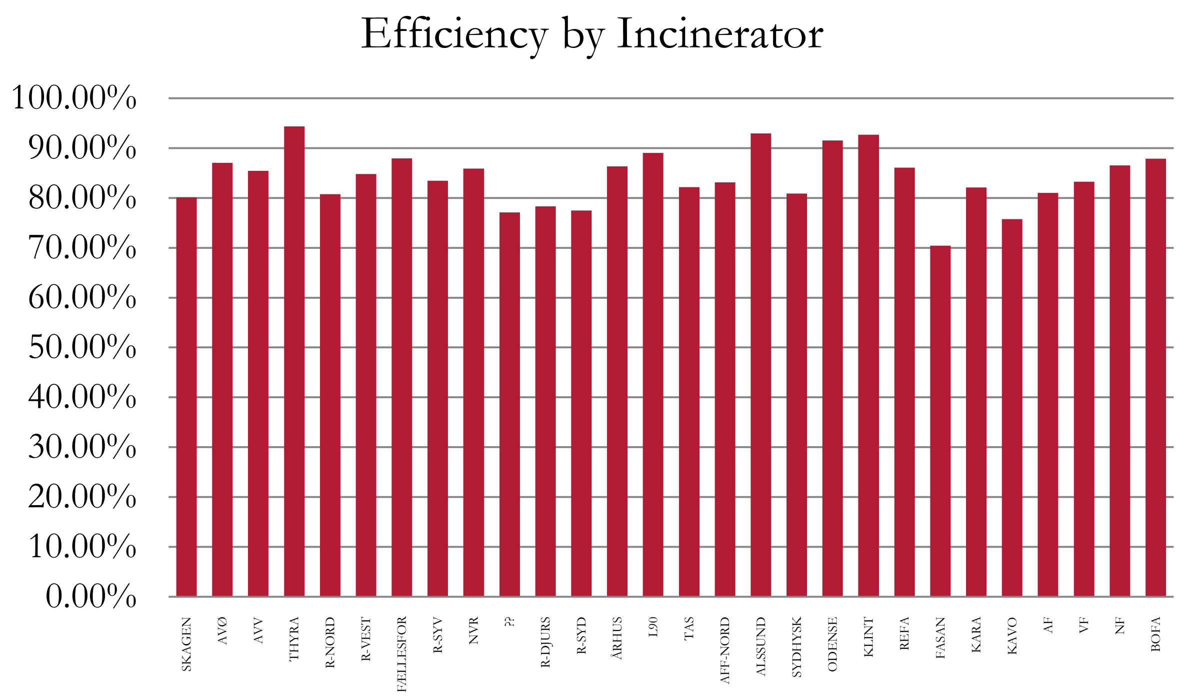

Figure 11: Efficiency by Incinerator

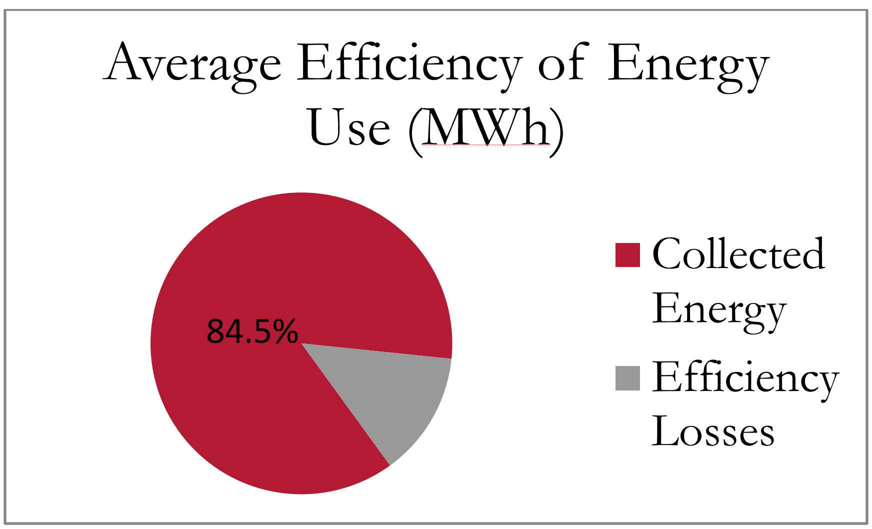

Figure 12: National Average Efficiency

Using this efficiency, the teamed determined that 5.5 GJ per tonne of garden waste could be expected to be collected in the system, see Equation 8 below.

Equation 8: Total Energy Provided by Garden Waste

$$\frac{6.5\ GJ}{Tonne\ of\ Garden\ Waste} \times 84.5\% = \frac{5.5\ GJ}{Tonne\ of\ Garden\ Waste}\ Added\ to\ the\ System$$

The team further broke this down into the amounts that were converted to heat and to electricity. The team looked at each incinerator individually, see Figure 13 below, and again decided to use the average values. 17% of collected energy goes to electricity and 83% goes to heat.

Figure 13: Energy Distribution between Heat and Electricity

Some incinerators, however, only generate heat and no electricity. Due to the importance of different fossil fuel replacement in the analysis, these incinerators were placed into their own category and looked at separately. Additionally, incinerators were separated into subcategories depending on whether or not they were producing excess heat. The creation of these categories was found to allow much greater accuracy in the analysis than was possible with a strictly national approach.

For simplicity purposes, the team assumed that the electricity added to the system would directly replace electricity currently being generated by the combustion of coal. This assumption is valid as coal is still widely used; 51% of the electricity generated in 2007 in Denmark came from the combustion of coal. If more electricity was being provided to the grid from waste incineration it would be the most logical choice to reduce the combustion of coal before reducing the use of other, cleaner energy sources. Thus, 17% of the 5.5 GJ, or 0.93 GJ of energy currently being provided by coal would now be provided by garden waste, as seen in Equation 9 below. According to the Danish Environmental Agency, coal emits 95 kg of carbon dioxide per GJ of energy provided under ideal circumstances and a brief review of coal plants shows an average efficiency of 45%, thus 211.11 kg CO_2/GJ would be released. This amounts to a savings of 198 kg CO_2/tonne garden waste as seen in Equation 10 below.

Equation 9: Energy Converted to Electricity

$$\frac{5.5\ GJ}{Tonne\ of\ Garden\ Waste} \times 0.17 = \frac{0.93\ GJ}{Tonne\ of\ Garden\ Waste}\ Converted\ to\ Electricity$$

Equation 10: CO2 Saved in Electricity Generation

$$\frac{0.93\ GJ}{Tonne\ of\ Garden\ Waste} \times \frac{211.11\ kg\ CO_2}{GJ} = \frac{197.1\ kg\ CO2}{Tonne\ of\ Garden\ Waste}\ 'Saved'\ in\ Electricity\ Generation$$

For heat generation, the team used the standard assumption that the energy provided by the garden waste would directly be replacing the burning of natural gas. 83% conversion to heat of the 5.5 GJ of energy amounts to 4.56 GJ of heat. The Danish Environmental Agency states that natural gas emits 57 kg of carbon dioxide per GJ under ideal circumstances and the team used the typical boiler efficiency of 75%, meaning that 76 kg CO_2/GJ are released when using natural gas. Thus 346.47 kg CO_2/ tonne of garden waste are saved; see Equation 11 and Equation 12 below.

Equation 11: Energy Converted to Heat

$$\frac{5.50\ GJ}{Tonne\ of\ Garden\ Waste} \times 83\% = \frac{4.56\ GJ}{Tonne\ of\ Garden\ Waste}\ Converted\ to\ Heat$$

Equation 12: CO2 Saved by Heat Generation

$$\frac{4.56\ GJ}{Tonne\ of\ Garden\ Waste} \times \frac{76\ kg\ CO_2}{GJ} = \frac{346.47\ kg\ CO2}{Tonne\ of\ Garden\ Waste}\ 'Saved'\ in\ Heat\ Generation$$

After interviewing staff at KARA/Noveren and Nordforbrænding the team learned that during the summer district heating is sometimes underutilized by households. Though the steam is still used for tasks like heating water, there is no need for heating the house. This forces many incineration plants to have to cool back off the steam. This greatly lowers the plants' efficiency. Additionally, the need for heat is not aligned with the availability of garden waste, which is at its most prevalent during the summer. In some cases, however, during summer months the steam can be put to an alternative use. Some industries take advantage of the steam in their processes, and thus can put large amounts of steam to use in the summer. To solve this problem, the waste can be moved from the collection point to a storage facility where it can be kept until the incineration plant has use for it during the winter months. This step is already being taken at some plants for items that do not require immediate incineration. The impact of any additional transportation however is very small when compared to the avoided emissions, as seen in section 4.3.2. This means that even if the distance the material was moved was increased beyond the considered scenario, there would be little effect on the final calculation result.

4.4.2. Environmental Costs

The environmental cost of the incineration of garden waste is seen in the burning of fuels in the transportation of the waste to the incineration facilities and in the electricity used to move the material around the plant. Based off of reports provided by RenoSam it was determined that a plant typically uses 15% of the electricity it produces. As previously determined, 0.93 GJ of electricity would be produced per tonne of garden waste incinerated. If 15% of this energy is directed back into the process, then only 85% of the energy, equivalent to 0.79 GJ/tonne of garden waste, can be considered to substitute coal. This reduces the amount saved, as determined in section 4.4.1, to 166.78 kg CO_2/tonne garden waste. See Equation 13 below.

Equation 13: Adjusted Electricity Savings

$$\frac{0.79\ GJ}{Tonne\ of\ Garden\ Waste} \times \frac{211.11\ kg\ CO_2}{GJ} = \frac{166.78\ kg\ CO2}{Tonne\ of\ Garden\ Waste}\ 'Saved'\ in\ Electricity\ Generation$$

No further environmental costs were considered since the electricity was assumed to come from the burning of the garden waste itself. Since this waste only contains biogenic carbon no further emissions need to be accounted for.

For transportation, the same calculations to assess the transportation of the garden waste to a composting site were used. Referring back to section 4.3.2 where the transportation cost of composting was calculated, the same numbers can be used. However, a distance of 40 km from collection site to incineration facility was used in place of the 30 km distance used in the composting assessment. This amounts to 8.01 kg CO_2/tonne of garden waste, see Equation 14 below.

Equation 14: Transportation Cost of Incineration

$$40\ km \times \frac{0.3\ L}{km} \times \frac{2.67\ kg\ CO_2}{Liter\ Diesel} \frac{2.67\ kg\ CO2}{Liter\ Diesel} \times \frac{1\ Truck}{8\ Tonnes\ Garden\ Waste} \times 2\ for\ Round\ Trip$$
$$= \frac{8.01\ kg\ CO2}{Tonne\ Garden\ Waste}$$

Again, the transportation cost assuming worst case scenario is less than one fiftieth of the ecological savings. This indicates that changes in the distance are negligible in the overall calculations. Additionally, because these calculations are based off a large distance estimate, the benefits of incineration can only improve.

The net savings resulting from incinerating garden waste is -506.0 kg CO_2 per tonne garden of waste, as seen in Equation 15 below. This is assuming that both electricity and heat and are generated and the heat is utilized. For scenarios where the plant generates only heat or if the heat is not completely utilized please see Appendix A: Calculations and Parameters Used.

Equation 15: Net Incineration Emissions

$$\frac{-346.47\ kg\ CO_2}{Tonne\ of\ Garden\ Waste} Avoided\ by\ Heat\ Generation$$
$$+ \frac{-166.78\ kg\ CO_2}{tonne\ of\ Garden\ Waste} Avoided\ by\ Electrcity\ Generation$$
$$+ \frac{8.01\ kg\ CO_2}{Tonne\ Garden\ Waste}\ from\ Transportation$$
$$= \frac{-506.00\ kg\ CO_2}{Tonne\ of\ Garden\ Waste} Emitted$$

Chapter 5: Conclusions

After reviewing the gathered data and results obtained from the computational process, the team came to the conclusion that incineration of dry garden wastes is a better option than composting when specific qualifications are met. The team analyzed the results looking at both the environmental costs and the value the end products have to the community.

5.1.Environmental Conclusions

The goal of this project was first and foremost to determine the most environmentally friendly option for garden waste disposal. Using the methods and analysis discussed in Chapters 3 and 4 the team created a calculation device to enable objective conclusions to be drawn.

5.1.1. Process

As discussed in section 3.4.1 above, due to the biogenic nature of carbon stored in garden waste the actual processes of incineration and well managed decomposition result in zero net emissions of green house gasses. Maintaining these processes, however, requires energy.

In a composting facility most of the carbon emissions are from the burning of fossil fuels in manipulation of the garden waste to turn and aerate the material. Using Danish averages this equates to roughly 33 kg CO_2 per tonne of garden waste treated. Incineration plants, however, run mostly on electricity which is supplied by the process itself. Because the energy that comes from garden waste is viewed as having zero emissions, the electricity used to power the incineration of garden waste is considered clean, and is simply subtracted from the electricity yield of the waste. This results in no greenhouse gas emissions.

Furthermore, as discussed in section 4.4.1 the creation of electricity and heat from garden waste prevents the burning of fossil fuels. This results in very large emissions savings. While compost was considered to directly replace the application of peat and fertilizer, the savings were simply not as large as can be seen in Figure 14. Using averages the team concluded that the incineration of garden waste can save up to approximately 405 kg CO_2 per tonne of waste more than composting.

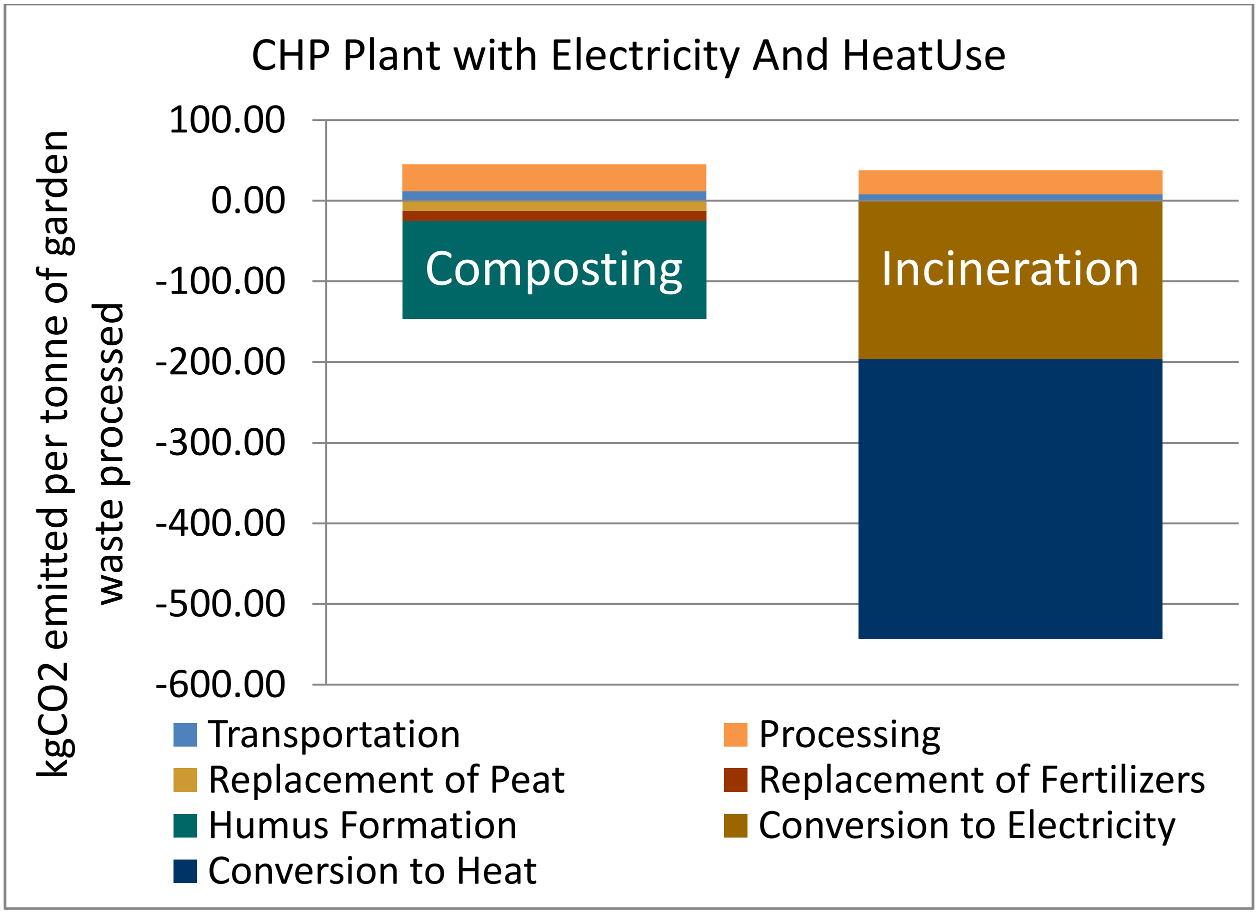

Figure 14: kg CO_2 per Tonne of Yard Waste Treated

5.1.2. Transportation

The transportation of garden waste was also taken into consideration as a source of greenhouse gas emissions. The team's calculations, however, showed that transportation accounts for a very small portion of the emissions and savings associated with the two processes. Transportation emissions can be seen in light blue in Figure 14. Transportation accounts for up to 12 kg CO_2 equivalent while savings due to the processes account for up to 506 kg CO_2 equivalent. Due to this finding the team concluded that transportation was not a very important factor or a reason to institute a regional analysis.

5.2.Qualitative Analysis

While the direct environmental analysis is important to this project there are some aspects of the problem that cannot be taken into account in a numerical form. These aspects require a separate qualitative analysis before they can be used in conjunction with the numerical analysis to form a sound recommendation.

5.2.1. Product Values

Compost is a necessary product, particularly for sports facilities such as golf courses and soccer fields. It is also used widely in both home gardens and nurseries. Occasionally, not all of the compost can be put to use in these ways and it is sometimes used to cover landfills. According to the Danish Environmental Agency, as much as 14% of the compost produced in 2001 was used for this purpose. Because compost offsets the use of peat and other fertilizers, and many of these alternatives are limited resources, some amount of compost is necessary. This has led the team to conclude that not all garden waste should be redirected away from composting. Because of other reasons such as incineration logistics the most fitting fraction to not be incinerated would be leafy material and grass clippings.

5.2.2. Sorting

While researching the composting process the team discovered that many composting facilities including Solum and RGS 90 are already sorting out much of the woody dry section of garden waste before composting it. This woody material is then often chipped and can be transported to Sweden or Germany for incineration. Being as the material is already being separated and that fuel costs for separation were integrated into the team's calculations, sorting of garden waste should cause little additional emissions. By incinerating the waste in the local incineration plant instead of shipping it abroad much less greenhouse gas will be emitted, increasing the savings against the current system.

5.2.3. Incineration Logistics

Incinerator ovens are quite susceptible to the buildup of non-burnable debris. Most damaging can be dirt and sand contained in the material being incinerated. Garden waste carries a portion of dirt and sand and if incinerated would mean more maintenance for incinerators. The majority of this foreign matter, however, is contained in leafy debris. This leafy material also contains the majority of moisture in garden waste, which also hinders the incineration process. For these reasons the team has concluded that leafy material should not be incinerated. The woody, dryer fractions of garden waste constitute approximately 30% of the total garden waste stream.

5.2.4. Categorical Conclusions

One issue with Incineration is the ability of the plant to utilize district heating during the summer months when garden waste would be most prevalent. Some plants are forced to cool a large amount of district heat back off as seen in Figure 15. Plants depicted in blue only produce heat, while those in red are CHP plants. If a plant produces both heat and electricity but is forced to cool off its heat it still saves about 60 kg CO_2 over composting. If however the plant only produces heat and already generates excess heat during the summer months then incineration provides no environmental savings and composting would save roughly 70 kg CO_2 while the heat is unused. Due to these differences the team divided their analysis into four categories. The scenarios considered were CHP with full product usage, CHP with heat re-cooling, heat only generation with product usage, and heat only generation with heat re-cooling.

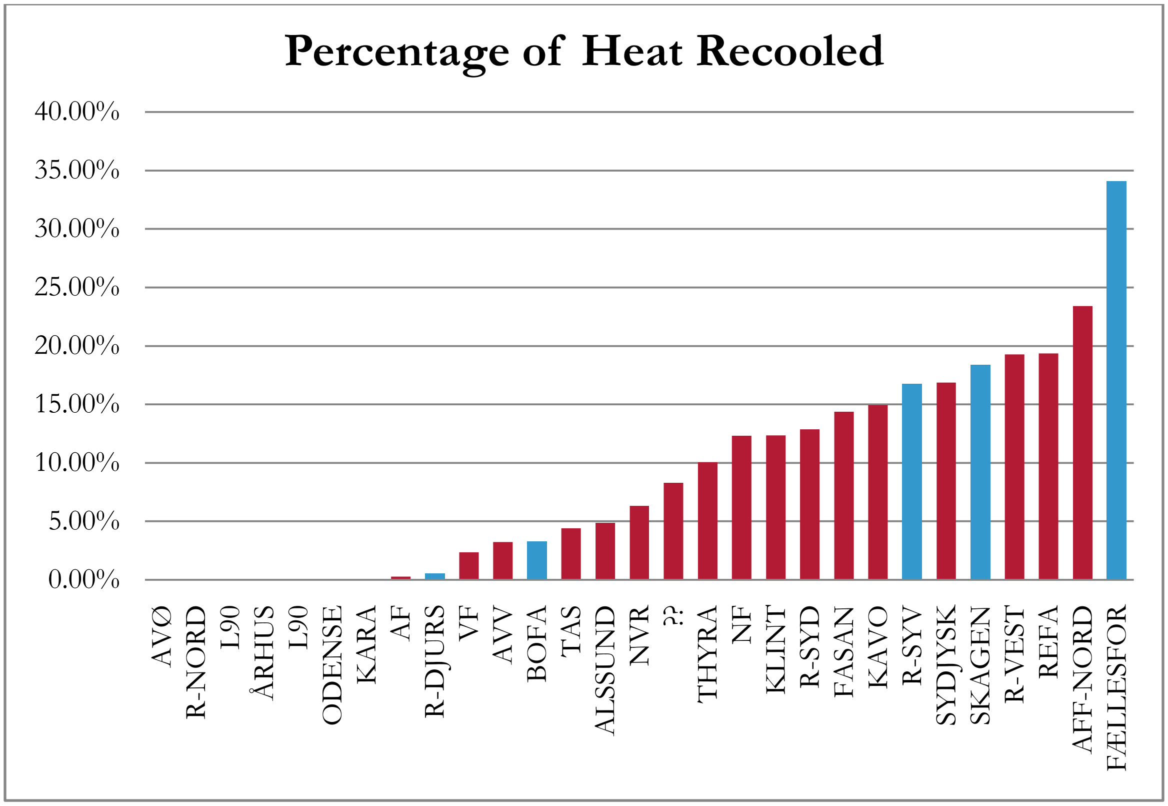

Figure 15: Percent Heat Cooled by Incinerator (2005)

5.3. Future Research

Despite the best efforts of the team, the time limitation of seven weeks onsite has left several aspects of the study that the team would like to see studied further in order to attain a more complete understanding of the most environmentally friendly waste management solution for garden waste.

5.3.1. Biogas

While performing research into waste disposal options the team learned of a technique known as biogasification. Though little research was done on the topic due to time constraints the team saw sufficient data to merit further analysis of its benefits as an alternative disposal option for garden waste. In this process the garden waste if first anaerobiclly decomposed and methane is captured. The resulting waste can then be incinerated or composted. In the quest to find the most environmentally friendly waste management systems it is important to explore all options. As such the team recommends that a more in-depth look is taken into biogasification as a competitor to straight composting or incineration.

5.4.Recommendations

After performing the research and calculations detailed above this team has split its recommendation into categories. In areas serviced by CHP plants, garden waste should be incinerated. In areas serviced by heat only plants, garden waste should be incinerated in most cases. Garden waste should be composted only if the heat only plant is cooling off excess heat, and is unable to store the waste until a time when the heat could be utilized. This storage additionally increases the wastes value to the incineration process due to drying and sap loss. The team recommends that prior to disposal, waste be separated in accordance with the guidelines set forth in section 4.1 of this report with “dry fractions” being incinerated when the above criteria for plant heat use are met, and that “wet fractions” being composted. The team also recommends that the topics listed in section 5.3 be investigated in greater detail to truly understand the most environmentally friendly garden waste disposal method.

The recommendations contained in this report are also based on several assumptions that may change over time. It is assumed that electricity produced directly replaces coal power, which is valid because currently approximately 50% of electricity is generated with coal. If in the future this is no longer the case then a new evaluation must take place. Heat was assumed to replace heat generated by natural gas, which currently accounts for 25% of the district heat production. If natural gas is no longer used to generate district heat then this recommendation should be reevaluated. Furthermore, if compost comes into more demand then a reevaluation is called for.

To aid in future calculations using the model developed by this team a Microsoft Excel spreadsheet calculator titled Garden Waste Calculator accompanies this report. This device allows the input of variables such as plant efficiencies, distances transported, and amount of energy used in the process and outputs kg CO_2 savings for each process. The availability of the calculator will also be useful for making recalculations if the energy generated by incineration is no longer replacing coal and natural gas. In this situation the new carbon emission factor for the replaced energy source could be substituted in. A copy of the spreadsheet will be given to RenoSam and submitted to WPI with this report.

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Appendix A: Calculations and Parameters Used

Table 1: Parameters Used in Calculations

General	
Parameter	Value
kg CO2 emitted per GJ electricity (national average)	152
kg CO2 emitted per GJ energy from coal (ideal)	95
Coal power plant efficiency	45%
kg CO2 emitted per GJ energy from natural gas (ideal)	57
Natural heat plant efficiency	75%
kg CO2 emitted per L diesel burned	2.67
kg CO2 emitted per L gasoline burned	2.32
L diesel per km for trucks used to transport garden waste	0.3
number of trucks per tonne of garden waste	0.125

Incineration	
Parameter	Value
% Energy Lost due to Efficiency	15.5%
% Energy Converted to Heat	83.0%
% Energy Converted to Electricity	17.0%
% Electrical Energy Not Used Internally	85.0%
km from collection point to incineration plant (average)	40
GJ Energy released per tonne of garden waste	6.5

Composting	
Parameter	Value
L diesel used per tonne garden waste composted	12.5
km from collection point to composting facility (average)	30
tonne compost created per tonne of garden waste	0.35
tonne peat replaced per tonne compost	0.25
kg CO2 emitted per tonne of peat used	147
tonne fertilizer replaced per tonne compost	0.1
kg CO2 emitted per tonne of fertilizer used	350

Table 2: CBA for CHP Incineration with Full Resource Usage

CBA for the case of a CHP plant that is selling its electricity and heat (no heat is being recooled)

Composting Process (Per Tonne)				
Operation	Resource Used	Fuel/ Energy	Emission Factor (kg CO2)	kg CO2
Transportation (Collection)	2.25L	diesel	2.67/L	6.01
Transportation (Delivery)	2.25L	diesel	2.67/L	6.01
Processing	12.50L	diesel	2.67/L	33.38
Replacement of Peat	-0.088T	peat	147.00/T	-12.86
Replacement of Fertilizers	-0.035T	fertilizer	350.00/T	-12.25
Humus Formation	1.000T	garden waste	-121.00/T	-121.00
			Total kg CO2 per tonne Garden Waste composted:	-100.72

Incineration Process (Per Tonne)				
Operation	Resource Used	Fuel/ Energy	Emission Factor (kg CO2)	kg CO2
Transportation	3.00L	diesel	2.67/L	8.01
Processing	0.14GJ	electricity (coal)	211.11/GJ	29.57
Conversion to Electricity	-0.93GJ	electricity (coal)	211.11/GJ	-197.12
Conversion to Heat	-4.56GJ	heat (gas)	76.00/GJ	-346.47
			Total kg CO2 per tonne Garden Waste incinerated:	-506.01

Table 3: CBA for CHP Incineration with Heat Re-Cooling

CBA for the case of a CHP plant that is selling the generated electricity, and recooling the generated heat

Composting Process (Per Tonne)				
Operation	Resource Used	Fuel/ Energy	Emission Factor (kg CO2)	kg CO2
Transportation (Collection)	**2.25L**	**diesel**	**2.67/L**	6.01
Transportation (Delivery)	**2.25L**	**diesel**	**2.67/L**	6.01
Processing	**12.50L**	**diesel**	**2.67/L**	33.38
Replacement of Peat	**-0.088T**	**peat**	**147.00/T**	-12.86
Replacement of Fertilizers	**-0.035T**	**fertilizer**	**350.00/T**	-12.25
Humus Formation	**1.000T**	**garden waste**	**-121.00/T**	-121.00
			Total kg CO2 per tonne Garden Waste composted:	-100.72

Incineration Process (Per Tonne)				
Operation	Resource Used	Fuel/ Energy	Emission Factor (kg CO2)	kg CO2
Transportation	**3.00L**	**diesel**	**2.67/L**	8.01
Processing	**0.14GJ**	**electricity (coal)**	**211.11/GJ**	29.57
Conversion to Electricity	**-0.93GJ**	**electricity (coal)**	**211.11/GJ**	-197.12
Conversion to Heat	**0.00GJ**	**heat (gas)**	**0.00/GJ**	0.00
			Total kg CO2 per tonne Garden Waste incinerated:	-159.54

Table 4: CBA for Heat Only Incineration with Full Heat Usage

CBA for the case of heat-only waste to energy plant that sells all of its heat (no heat is being recooled)

Composting Process (Per Tonne)				
Operation	Resource Used	Fuel/ Energy	Emission Factor (kg CO2)	kg CO2
Transportation (Collection)	2.25L	diesel	2.67/L	6.01
Transportation (Delivery)	2.25L	diesel	2.67/L	6.01
Processing	12.50L	diesel	2.67/L	33.38
Replacement of Peat	-0.088T	peat	147.00/T	-12.86
Replacement of Fertilizers	-0.035T	fertilizer	350.00/T	-12.25
Humus Formation	1.000T	garden waste	-121.00/T	-121.00
			Total kg CO2 per tonne Garden Waste composted:	-100.72

Incineration Process (Per Tonne)				
Operation	Resource Used	Fuel/ Energy	Emission Factor (kg CO2)	kg CO2
Transportation	3.00L	diesel	2.67/L	8.01
Processing	0.14GJ	electricity (avg)	152.00/GJ	21.29
Conversion to Heat	-5.49GJ	heat (gas)	76.00/GJ	-417.43
			Total kg CO2 per tonne Garden Waste incinerated:	-388.13

Table 5: CBA for Heat Only Incineration with Heat Re-Cooling

CBA for the case of heat-only waste to energy plant that is recooling all of the generated heat

Composting Process (Per Tonne)				
Operation	Resource Used	Fuel/ Energy	Emission Factor (kg CO2)	kg CO2
Transportation (Collection)	**2.25L**	**diesel**	**2.67/L**	6.01
Transportation (Delivery)	**2.25L**	**diesel**	**2.67/L**	6.01
Processing	**12.50L**	**diesel**	**2.67/L**	33.38
Replacement of Peat	**-0.088T**	**peat**	**147.00/T**	-12.86
Replacement of Fertilizers	**-0.035T**	**fertilizer**	**350.00/T**	-12.25
Humus Formation	**1.000T**	**garden waste**	**-121.00/T**	-121.00
			Total kg CO2 per tonne Garden Waste composted:	-100.72

Incineration Process (Per Tonne)				
Operation	Resource Used	Fuel/ Energy	Emission Factor (kg CO2)	kg CO2
Transportation	**3.00L**	**diesel**	**2.67/L**	8.01
Processing	**0.14GJ**	**electricity (avg)**	**152.00/GJ**	21.29
Conversion to Heat	**0.00GJ**	**heat (gas)**	**0.00/GJ**	0.00
			Total kg CO2 per tonne Garden Waste incinerated:	29.30

Appendix B: Worcester Composting Site Visit Summary

The Millbury Composting Site in Millbury, Massachusetts services parts of Worcester County. The site is operated by the Worcester Department of Public Works and Parks. The material being composted is a combination of collected leaf matter, and garden waste that is dropped off by citizens of Worcester. The large volume of leaf matter was finely ground before composting to eliminate the Asian Longhorn Beetle Problem in Worcester. The material for composting is formed into long piles that are turned periodically by front-end loader style trucks as seen in Figure 16 below.

Figure 16: Compost Pile Being Moved by a Front End Loader

The moisture from rain and the aeration from the turning fuel the composting process. The temperature of the piles is moderated and kept between approximately 100^{O}F and 160^{O}F. The site is mindful of odor problems and attempts to work on areas of the site that are downwind of their neighbors each day. Additionally, wood ash is added to the top of the piles to help control the odor. After the composting is complete, the material goes a screener, see Figure 17 below, that removes any large chunks of wood or other materials that weren't composted such as plastics and other non biodegradable items that were mixed in with the original material. The finished material is provided first for citizens to collect for private use, and second sold to wholesalers.

Figure 17: The Screener

Appendix C: Visit to KARA/Noveren Incineration Site

Date: 03/27/09

Location: Roskilde, Denmark

Description: Interview with Flemming Bruun, followed by a short promotional video and a guided tour of the waste to energy facility

Interview

- Costs about 300 dkk per ton to compost garden waste
  - No one will buy it, has to be given away
- Incinerating takes possible nutrients away from the ground, but the flue gas is pretty clean
- With composting, there's need to use machines to turn and truck waste
- Grass would not burn very well, but tree parts would be very good
  - Dry is best, can burn wet but not efficiently
- Natural gas is only used when starting up the incinerators or when it falls below 850 c
  - If below 850 c proper regulations are not met for clean disposal
- Right now the main line only runs at 65% capacity and the two smaller ones are off
  - Lack of waste to burn right now
  - This may change with time, waste flow is not constant
- No assisted burners, only waste and air go in.
- 15 mw electricity and 45 mw of heat output
  - There is a drop off site at this facility, and the people dropping off separate the waste
  - Trucks also bring in from surrounding drop off sites
  - Paper bags are also available that will be picked up when placed on the side of the road
- Composting facility is far away.
- 9-10 drop off sites in the Roskilde area
- Garden waste could be separated easily, by allowing certain fractions to be put in the burnables receiver
- District heating operates during the summer as well
  - Used for hot water, etc
- Most incinerators are near big cities
  - Heat generated at Roskilde goes to Copenhagen
  - Can be up to 100 km away but pumps must work harder and there is some heat loss
  - District heating is a big network, and a big commitment
- Cranes used to feed the waste are electric and run automatically outside of business hours
- Facility was constructed in the 60's
  - The 20 tonne incinerator was made in 99
  - The first 7 tonne was built in 81, the second in 89
  - Another is in the works for 2013 and will be a 25 tonne
- Right now not getting as much waste as last year because one of KARA's partners is contracted to send it somewhere else. Will get more next year

- Capacity not a problem

Movie

- No competitors exist within Roskilde area
- Publically owned
- 160,000 tonnes a year of waste
- 16000 homes with electricity, 19000 homes with heat
- Slag is collected and used in roads

Tour

- Have a back up for district heat that runs on oil
- 600 tonnes a day, 2800 tonnes a week currently
    - Almost half of what they had last year
- 4000 a week can be burned with 2000 storage in large line
- Small ones produces 5000 kcal/kg if dry
- Large line can go through 20 tonnes / hr
- Pictures available

Appendix D: Interview with Janus Kirkeby

Date: 04/01/09
Location: Videncenter for Affald (Knowledge Center for Waste)
Description: Interview with Janus Kirkeby, an employee of the Videncenter for Affald. This organization manages information for the Danish EPA. Janus is also an expert in the field of waste management, especially the area of assessing waste disposal options. He is familiar with our problem and the WaRM calculator.

- Videncenter for Affald
  - Knowledge Center for Waste
  - Part of Rambol
  - Collect data for Danish EPA
  - Publish print and online Journals
- Herning (check that this is right) Municipality in Denmark has already tried to incinerate their garden waste
  - Problems arise when the garden waste is polluted with rocks and sand as this causes problems in the incinerator process and requires additional cleaning
- Biggest factor that can make a difference is
  - How much extra power/heat can be generated
  - Is the heat being utilized
    - Some plants cool their heat back down, especially in the summer time
    - Plants next to industrial sites (such as a large green house) use all their heat all year long
    - Plants with large established heating grids use more of their heat then those with smaller heating grids
- Compost
  - Is it really used as a substitute for fertilizer
    - If yes, then it's a good resource
    - If people are using it and fertilizer anyways then not so important
    - Can be sold to large scale green houses to help them avoid other additives
  - Is it being used instead of Peat Moss?
    - If it is, then it is a very valuable resource as using Peat releases CO_2 and is overall bad for the environment
  - Home composting
    - Municipalities can only encourage citizens to bring compost to incinerate vs. composting it themselves
    - Reduction in transportation is a large pro of home composting
    - But only if they are actually then using it and need it, see comment about fertilizer above
  - Using in agriculture
    - Very good for poor quality soil

        - However Danish soil is very rich, adding compost leads to an excess of carbon in the soil
    - It is true that it can't be sold
        - But people do come and pick it up for free
        - Compost with food waste and sewage sludge much more trouble getting rid of
            - Farmers don't want it because people won't buy produce/meat that has been grown on soil with it in it
- Methane
    - Not a problem in well managed piles
    - Could be a problem in home composting
    - Mostly an issue when food waste is used
        - Best for environment if food was centrally composted if at all possible
- Sorting garden waste
    - Citizens aren't going to want to do it on their own
    - But it would be best for the whole system in terms of environmental impacts
    - Citizens sorting themselves vs. Sorting at drop off sites
- Collection Schemes
    - About half of all municipalities have collection schemes (roadside pickup)
        - Is better for environment
        - If everyone drive their waste in then the environmental balance if flipped
        - Most of these collection programs are in the larger cities
            - People have living fences that have to be trimmed regularly and no yard to do their own composting
- Regions
    - Defiantly variances across areas
        - Mostly in heating systems
            - Maybe break it down into places that use all their heat year round and those that don't
        - Also in how efficient the incineration plants are
- EASEWASTE and WaRM
    - Big machines and it takes time to develop and be confident in your numbers
    - Nordic Council has created a simple model in excel that is only for biowaste
        - Establish carbon, nitrogen, water content and ash composition and try using this

Appendix E: Visit to Nordforbrænding Waste Management Sites

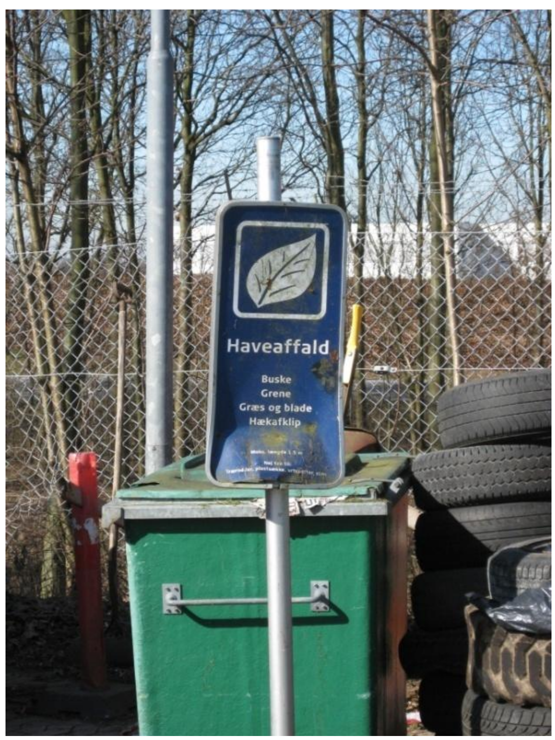
Date: 04/02/09

Location: Hørsholm, Denmark

Description: Interview with Peter Storm followed by guided tours of the incineration plant and two recycling collection centers.

- There are 30 incinerators in Denmark which go through 3.4 million tonnes of waste a year
- Nordforbrænding was founded in 1965
  - Owned by 5 municipalities
  - Services 200,000 inhabitants
- Both household (50%) and industrial (50%) wastes are serviced at the facility
- Also responsible for distributing and selling district heat produced
  - Main district heating lines are 47 km long
- Average cost of incineration is 200 DKK/tonne
- Facility is very close to community
- Electric crane is used to load material (diesel backup)
- Sorting would be necessary
  - Current sorting separates wood greater than 5 cm in diameter
  - Some issues arise in making people sort
- Gravel and sand in the incinerator is not a problem
  - Wood is crushed and gravel is separated out
- The facility has the capacity to accommodate garden waste
  - Waste down 20% due to recession
  - The previous year did not leave much extra room for Garden Waste
  - New burners are being built at a lot of plants and would expand capacity
- Nearly same amount of waste is collected year round
  - Site has some ability for storage, but not enough
  - End up needing to cool of some of the district heating
  - Some business use it in the summer as well, this is good.
- No assisted burners are used in the plant (only when starting or not working well)
- 130.000 tonnes a year goes through the plant
- Road side collection and private delivery are both used
- Approximately 16% of waste converts to slag
- Home composting would be more efficient (in his opinion)
- It is difficult to get rid of compost
- 500 tonnes of compost are given out to homes, 20.000 tonnes of garden waste are collected
- Diesel is used in loaders to move compost
- Compost is complicated to make
- Sewerage sludge is not mixed with garden waste in composting here
- Too much transportation goes on with compost currently
  - Sewerage sludge is sold to Germany

- Approximately 8 tonnes are put into each trailer when trucking garden waste
- Some people do home composting, but most feel it takes too much work
- There are problems with heavy metals if things other than garden waste are used in compost
- Garden waste travels up to 30 km to the composting facility



Appendix F: Visit to Solum Composting Facility

Date: 04/17/09

Description: Interview with Christian Christensen followed by a tour around the composting facility

Interview

- Met Henning over 20 years ago and made composting plant
- We are currently in the high season for composting
- Started as the owner of a nursery, found that mixing compost and peat resulted in a favorable soil additive.
    - Met Henning and started a composting plant
- 17% water in garden waste (Approximately)
    - About 20 years ago garden waste was incinerated
        - This moisture content proved to take more energy than the garden waste gave
- Solum makes many different mixtures with compost to make different growing mediums for various applications (soccer fields, golf courses, etc.)
- Receive roughly 100,000 tonnes of garden waste
    - Some is chipped and sent to Sweden and Germany for incineration
        - Sent away because it cannot be legally burnt here
- Some compost is bagged and sold to supermarkets in Norway and Denmark
- Incineration is not a good option for all garden waste
    - Approximately 70% is too wet to burn effectively
        - Water must be boiled off first
    - Also contains small stones and dirt which is not good for incinerator
- Already split garden waste into fractions
    - Have done many studies to see what fractions are best for incinerate
    - Percentages vary throughout the year
        - Sometimes more leaves, sometimes mostly branches
- Each incineration plant is also different, can incinerate different wastes with different efficiencies
- 25-35% of garden waste can be incinerated (low enough moisture content)
- Biogas
    - Mix garden waste and other household wastes, get easy sugars and such out as biogas, and incinerate or compost the left over material
- Standard mobile equipment is used in Solum's facilities, so that they can easily and quickly be serviced
- Some parts of the year aeration from sticks is important
- About 70% of garden waste is used for composting
- Garden waste is mixed with other wastes, mostly for biogas

- A large amount of compost is sent to farmers
    - They have to log how much they want and are allowed to use
- Well managed compost leads to no problems with methane
    - Very important to compost the right way
- Richness of the soil in Denmark was not an issue until now
    - Compost is more needed now then in recent past
- Phosphor prices are going up
- Solum is currently selling all of its compost
    - Sports facilities are large customers
- Other companies think of compost as a waste that they have to get rid of
    - To Solum compost is a product that their company wants to make
    - This allows them to have no trouble in selling their product
- Compost is almost directly replacing peat
- People right now are thinking about energy, a few years ago they were thinking about the soil; its cyclical
    - If you think about it, energy comes from soil and we only have so much so it's very important
- Numbers are available on the amount of fuel used in Solum's environmental report
- Substitution of compost to peat is not Kg to Kg, but more cubit to cubit
- Big difference between garden waste compost and others
    - Garden waste has no nitrogen but it contains many other important properties
- Phosphor is a good ground material, but it's going to run out soon
- Sand and moisture are both big obstacles for incinerating garden waste
    - Both tend to be in the same fraction though
- People wouldn't like to separate their waste more

<u>Tour</u>

- Compost at Solum runs on a 3 year maturation cycle
- Only allowed to turn the compost in January
- 65000 tonnes a year

Appendix G: Visit to RGS 90

Date: 04/24/09

Description: Interview with Kim Nytofte Dæk followed by a tour around the facility

Interview

- Composting is probably the most C02 neutral process for garden waste disposal
    - Composting also brings C02 back to the soil
- Incinerating biomass for energy is probably the second best option
- RGS 90 is one of the biggest waste management companies in Denmark
    - Service a large amount of demolition debris
- Sort incoming waste for different processes; incineration, composting, etc.
- RGS 90 has affiliates in Sweden
- 250,000 lories bring waste each year
- 1987 waste tax was implemented
    - Now 375 DKK per tonne stored, 330 DKK per tonne incinerated
    - The incineration tonne will soon be switching to per calorie
- Next year the EU is going to start considering incineration recycling
- RGS 90 collects a lot of park waste from the city
- Also process stones, etc
- Receive incineration slag for disposal
- 40,000 tonnes of garden waste are collected every year
    - 46,000 tonnes of compost are created
- Wood matter is sent to Sweden and Germany for incineration
- For more technical information we should email later
    - KNB@dsvm.dk
- Most compost produced goes to construction, road work, and stadiums
- The composting process takes 6 months to complete
- Separation of woody material for incineration is done by rule of thumb
- The windrows are turned weekly

Appendix H: RenoSam Conference Program

Biomasse (slam) og haveaffald – hvad skal vi dog gøre med det?

Reno Sam

Konference om biomasse/slam og haveaffald
Mandag den 11. maj 2009
Konference er arrangeret med hjælp fra Rambøll A/S

RenoSam :: Vesterbrogade 24, 2 sal tv. :: DK-1620 København V :: Tlf: +45 46 75 66 61 :: Fax: +45 46 75 64 62 :: renosam@renosam.dk

PROGRAM

09:30 – 10:00 Ankomst og registrering

10:00 – 10:15 Hvad gør vi med biomassen/slammet i dag?
Der gives en kort gennemgang af udviklingen i biomassemængder og behandlingsformer op til i dag *v/ Henning Jørgensen, RenoSam*

10:15 – 13:00 **Hvordan skal vi behandle biomasse/slam i fremtiden?**

Hvad vil regeringen med biomassen?
I såvel regeringens affaldsstrategier som i affaldsrammedirektivet er der lagt overordnede planer for håndteringen af biomasse. Men hvilke?
v/Inge Werther, DAKOFA

Forbrænding eller anvendelse til jordbrug – videnskab eller tro?
Der er lavet livscyklusanalyser for forskellige anvendelser af biomasse. Hvad er resultatet?
v/Per Haugsted Petersen, Rambøll

Hvilken værdi har biomasse for landbruget og miljøet – gødning, kulstoflagring, klima m.m.?
v/Lars Stoumann Jensen, professor ved Københavns Universitet

Hvad skal landmænd med biomasse – og hvorfor siger nogen af dem nej?
Hvad er motiverne for, at landmænd siger nej og ja til at få biomasse på deres jorde?
v/ Leif Knudsen, Dansk Landbrugsrådgivning, center for Planteavl

I Fasan afsætter man komposteret slam til landmænd. Vi skal høre, hvilke erfaringer de har gjort sig.
v/Bente Munk, Fasan

Afgiftsændringer, biomasse og gyllefiber
Biomassen skal ikke brændes i Tyskland, men i Danmark. Det var tilsyneladende baggrunden for en afgiftsomlægning, der skal fremme forbrændingen af biomasse i Danmark. Men er kapaciteten til rådighed, og er anlæggene egnet? Erfaringer fra Vendsyssel.
v/Torben Nørgaard, AVV

Hvilke krav stilles til fremtidens håndtering af biomasse?
Hvor skal vi lede efter fremtidens krav – biomassedirektivet, end-of-waste definitionen, krav til asken fra forbrændingsanlæg eller..?
v/Inge Werther, DAKOFA

13:00 – 14:00 Frokost

Reno Sam

RenoSam :: Vesterbrogade 24, 2 sal tv. :: DK-1620 København V :: Tlf: +45 46 75 66 61 :: Fax: +45 46 75 64 82 :: renosam@renosam.dk

14:00 – 16:00 Haveaffald – hvad skal vi bede borgerne om?

Hjemmekompostering, fælleskompostering, forbrænding eller noget helt fjerde. Meninger om, hvad vi skal gøre med haveaffaldet, er mange – alt efter geografi og indgangsvinkel.

Miljøvurderinger

RenoSam har tre amerikanske studerende på besøg, som er ved at færdiggøre en opgave, hvor de laver miljøvurderinger af forskellige håndteringsformer. Deres resultater fremlægges. Oplægget er på engelsk.
v/Nathan Webb, Nikki Clardy og Seth Chapman, Worcester Polytechnic Institute, Worcester Massachusetts, USA

Er det nu også helt rigtigt..?

Christian Christensen (SOLUM) og Klaus W, Hansen (Kara/Noveren) har læst resultaterne på forhånd, og er kærlige, men kritiske, opponenter på resultaterne.

PRAKTISKE OPLYSNINGER

Målgruppe:	**Kommuner, affaldsselskaber og rådgivere**
Tid:	**Den 11. maj 2009 fra kl. 10.00 til 16.00**
Sted:	**Rambøll, Englandsgade 25, 5100 Odense C.**
Pris:	**1000 kr. for medlemmer af RenoSam. Andre 1200 kr.**
Tilmelding:	**Tilmelding kan ske på www.renosam.dk** ***Tilmeldingsfrist er onsdag den 6. maj 2009. tilmeldingen er bindende efter den 1. maj 2009.***
Spørgsmål:	**Kontakt Henning Jørgensen hj@renosam.dk** **eller Niels Remtoft nir@renosam.dk**

Reno Sam

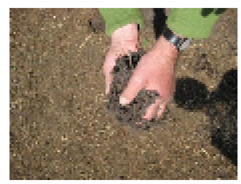
RenoSam :: Vesterbrogade 24, 2 sal tv. :: DK-1620 København V :: Tlf: +45 46 75 66 61 :: Fax: +45 46 75 64 82 :: renosam@renosam.dk

Appendix I: Conference Handout

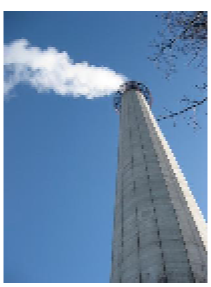
Kompostering eller forbrænding af have- og parkaffald i Danmark?

Den amerikanske miljøstyrelse (US EPA) offentliggjorde for nylig en rapport, der sammenligner forskellige former for affaldsbehandling. Rapporten anfører, at hvad angår haveaffald kan forbrænding med energiudnyttelse potentielt være bedre for miljøet end kompostering. Efter at have læst rapporten satte RenoSam sig for at undersøge, om en lignende konklusion ville gælde for det danske affaldssystem. Dette studie søger at sammenligne miljøpåvirkningerne fra disse to behandlingsformer for haveaffald.

For at nå målsætningen har vi analyseret tidligere studier samt interviewet eksperter på komposterings- og forbrændingsanlæg såvel som andre, der beskæftiger sig med affaldshåndtering. Vi har besøgt affaldsbehandlingsanlæg hos KARA/NOVEREN, Nordforbrænding, Solum og RGS 90. Vores studie tyder på, at ikke alle haveaffaldsfraktioner er egnede til forbrænding. Græs og blade har et højt vandindhold og indeholder ofte grus og sand, der kan beskadige ovnene. Derfor anses kun de mere tørre fraktioner af haveaffald, herunder grene og træstykker, som egnede til forbrænding.



Der er blevet indsamlet data om transport og energianvendelse til hver proces samt data om emissions-besparelser for hvert produkt. Mht. kompostering ses besparelser i forhold til undgået anvendelse af gødning og tørv samt produktion af humus. Forbrænding, med energiudnyttelse, producerer varme og elektricitet, der ellers ville kræve afbrænding af fossile brændsler, og dermed undgås de emissioner, der stammer fra forbrænding af fossilt kulstof.



I lighed med US EPA's konklusioner kom vi, i vores studie, frem til, at forbrænding med energiudnyttelse i de fleste tilfælde er mere miljøvenlig end kompostering. Det eneste scenarium, hvor kompostering er bedre end forbrænding, er, når et forbrændingsanlæg ikke producerer elektricitet og allerede producerer overskudsvarme. Dette resultat havde dog som forudsætning, at den producerede el ville erstatte kul, og varmeproduktionen ville erstatte naturgas. Hvis kul og andre fossile brændsler engang i fremtiden bliver udfaset fra energiproduktionen, bør disse to behandlingsformer for haveaffald underkastes en ny undersøgelse. Vi har endvidere konkluderet, at for at optimere emissionsnedbringelsen fra forbrænding af haveaffald bør affaldet oplagres, indtil al den producerede varme kan udnyttes.