

**Identifying Alternative Waste Conversion Technologies for Use at
California Polytechnic State University San Luis Obispo**

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ABSTRACT

This project was undertaken to identify and study alternative technologies for converting waste streams available on the Cal Poly San Luis Obispo campus into energy. As a large campus on the Central Coast of California Cal Poly not only produces lots of waste, but has limited options for its disposal. Furthermore, the campus is in the midst of an on-going green initiative, and more efficient use of its waste products would be a welcome development for the entire campus community.

This report gathers information on waste streams originating at Cal Poly and information about waste to energy conversion technologies. The purpose of the report is to combine the two avenues of study and assess the viability of using any or all of the technologies discussed in order to reduce outgoing waste and increase energy independence of the campus. Some added benefits would be to give students another opportunity to learn by doing in a real world scenario.

The University Community of Cal Poly in San Luis Obispo is constantly changing. The population increases and decreases and the composition changes over time depending on many variables. One of the many trends the campus is experiencing is increasing enrollment over time. As more people frequent campus the waste produced on campus increases also. The campus population was calculated to produce approximately 25,000 pounds of waste per day in 2005 and was recorded to produce approximately 10 million pounds of waste over the course of the 2008 school year.

There are many methods that the campus could use to dispose of this waste. The campus currently uses a combination of some traditional as well as non-traditional methods to solve the issues associated with campus waste production and disposal. Although the campus is fairly progressive in its methods there is always room for improvement.

Some alternative technologies that show promise for use are gasification and anaerobic digestion. Neither of these two technologies is currently used on campus to dispose of waste but both are widely used in industry. The two technologies would provide students and faculty the chance for research, development and could allow the campus community to benefit economically from the processing of various waste streams.

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Waste is produced as a natural part of life. We as a society have methods of reducing or converting the state of many forms of waste. Some currently used techniques are chemically treating manure, and burying or burning solid waste.

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INTRODUCTION

Background

Waste is produced as a natural part of all biological life cycles. In fact, Waste production is one of the most basic principles of all biological systems. Every living organism produces waste in one form or another. In the animal kingdom humans are especially adept at waste production. As the most highly developed animal on earth, the human being has progressed far beyond the production of simple biological wastes. We produce copious amounts of wastes in hundreds of different types. These wastes take many forms; synthetics, plastics, industrial and nuclear just to name a few. As humanity has developed; humans have been forced to find new ways to deal with their waste and its ever-changing forms.

Originally, the goal of refuse disposal was simple and followed the out of sight, out of mind, philosophy. The idea was to move the waste far enough away from the creating populous that it could be forgotten and left for nature to decompose over time. This technique has taken many forms. In ancient times cave dwellers hauled trash to the edge of the cave and left it there. In later years trash was simply discarded onto the floor of the residence. In fact when headroom became limited the building was raised and eventually moved rather than moving the rubbish. Now trash, or municipal solid waste as it is often referred to, is hauled for miles to central processing and disposal centers.

These disposal centers are commonly referred to as dumps or landfills. Various forms of landfills have been developed throughout history. Today's landfills are quite advanced in comparison to older designs but they all essentially use the same principal; bury the waste and allow natural processes to dispose of it. This is just another variation of the out of sight, out of mind principle of times past. (Neal, 1987)

During the industrial revolution and the early 20th century the promise of jobs and excitement of city life appealed to many people and as a result the world began a trend of urbanization. The populous of the US and the world moved away from small country towns and into the cities and immediately surrounding areas. People's life styles became more sedentary as populations became more concentrated into smaller urban areas. This caused the problems associated with waste disposal to become more complex. Most people were content to throw their wastes from the windows of their upper story apartments. If there were a few that did walk the trash downstairs there were far fewer that would walk the trash to edge of town to the dumpsite. This led to waste piling up in the streets. It

was only in response to the problems associated with this practice that organized collection services were organized.

It was apparent to many people that we could no longer rely completely on nature to solve our waste disposal problems for us. These city lifestyles produced wastes in amounts and with compositions that didn't efficiently decompose under natural circumstances. Another important issue was the discovery that the germs in the waste spread disease. These facts led to a movement to alter our waste handling techniques. These changes have led to today's systems of localized central dumping sites and complex collection, processing and disposal systems for different forms of waste.

Even as a modern, technologically advanced society we still produce lots of waste, millions of tons worldwide in fact. Over time we have developed methods of reducing or converting these wastes. There are many such methods of waste disposal used today, often in conjunction with one another.

The more traditional forms are burning, piling, land filling and ocean dumping. Some methods offer a greater return on investment by allowing energy or other products to be derived from the waste. Some of these techniques are recycling, composting, incineration and anaerobic digestion. Another noteworthy practice, which is more of an aid to these than its own method, is source reduction. These all have their benefits and drawbacks; which lend different techniques and practices to different applications.

Justification

Society is growing in population every day. The U.S. census bureau reported that the United States increased in population 22% between 1990 and 2008. Not accounting for any other changes, as the number of organisms in a population increases the amount of wastes produced increases. Humans are not exempted from this rule. As the number of people in the world increases the amount of waste produced increases in conjunction. In a national study on municipal solid waste the EPA found that trash production per person in the United States remained fairly constant between 1990 and 2000. The amount was fairly steady at approximately 4.5 pounds per person per day. This number at first appears promising for a number of reasons. Programs are in place to reduce the percentage of waste going to landfills, to more efficiently use landfill space and to reduce waste before collection by encouraging alternative uses.

However, our programs' efforts were more than overshadowed by the population increase during this same time period. Municipal solid waste production in the United States increased from approximately 205 million tons in 1990 to 250 million tons in 2008. (EPA, 2008)

Like so many other things in life university enrollment seems only to increase over time. This could be caused by many things; poor economy, more competitive job markets, increasing support for those previously unable to attend or just a growing desire for more advanced knowledge of academic concepts. As university enrollment increases, a consequence is that more people leave their "footprints" on campuses that offer these degrees. Campuses like Cal Poly are experiencing this phenomenon across the nation and the world. As university enrollment increases the effect on the surrounding communities cannot be ignored. After all, students rarely spend all their time on campus. These people produce hundreds of tons of waste annually, all of which must be processed in some way. According to environmental sustainability committee at Michigan Tech the average college student produces 640 pounds of solid waste each year or approximately 1.75 pounds per day. With enrollment sometimes reaching over 19,000 students and approximately 1000 faculty Cal Poly's campus community could produce 35,000 pounds of waste per day. However, we must not forget that the humans aren't the only animals producing wastes.

Cal Poly San Luis Obispo has a diverse population of students, faculty and as a University with a strong background in agriculture. It also houses a multitude of animals. Animal populations fluctuate throughout the year but can number over 30,000. This estimate includes approximately 300 dairy cattle, 600 swine, 800 beef cattle, 500 sheep, 100 horses and 30,000 poultry. These animals all produce waste on a daily basis and the constitution of it varies by species, diet, state of health and many constantly fluctuating factors.

The waste streams produced at Cal Poly S.L.O. are very diverse due to the assortment of people, animals and processes that occur on campus on a daily basis. These waste streams consist of any number of different individual components. The wastes will be grouped into the following categories: Municipal Solid Waste, Manure, Biomass and wastewater.

As society becomes more aware of how our actions affect the world we live in, many of us strive to find ways to lessen our footprint on the world. This green movement has spread to Cal Poly as well. Over time the pressure to keep waste out of landfills and to find more productive uses has increased and the campus waste management strategy has evolved in an effort to keep pace. This has, in part led to the implementation of various waste management programs at Cal Poly. The Campus currently operates a recycling and composting program and at one time operated an anaerobic digester program.

There remains however, significant opportunity for study, research, and development of these systems as well as for the incorporation of new technologies. New technologies could take currently unused wastes and convert them into more beneficial products or simply provide an alternative method of disposal. Altering the Cal Poly waste management system to include these new technologies of waste conversion could benefit students, faculty, Cal Poly and the community at large.

Objectives

The first major objective of this senior project is to identify technologies and processes that can be used to convert waste products into more beneficial materials or provide the campus with an alternative means of disposal. The second objective is a rudimentary analysis of their feasibility for use at Cal Poly, SLO. In order to answer these two questions the following information must be gathered.

- Identify Waste Streams Produced from Campus
 - Categorize Wastes into Disposal Groups
 - Approximate Volume of Wastes and Disposal Groups
- Identify Waste Conversion Technologies for Wastes from Campus
- Describe Technologies, their Functions and Usage
- Determine What Other Methods of Waste Conversion Would Most Likely be Used to Process the Available Wastes from Cal Poly.

Constraints

The project is subject to the following constraints and limitations

- Only Waste Streams Originating from Cal Poly Will be Considered for the Study
- No Waste Importation will be Considered

LITERATURE REVIEW

Waste Composition, Production and Handling

Municipal Solid Waste

Describe, Define. The term municipal solid waste is itself a very broad idea. This term refers to anything a municipality discards. MSW. can include everything that commonly comes to mind when one thinks of trash. Packaging wastes, food scraps, furniture, tires, refrigerators and countless other items have all gone to a dump somewhere in the United States at one time or another.

Within this very broad waste stream there are multiple different ways to categorize the waste. For example, lawn clippings and other yard and landscaping wastes are commonly called green wastes, automotive fluids are grouped with nuclear wastes as hazardous while wastes originating from electronic devices like computers are called e-wastes and can be considered another realm of hazardous waste. Wastes can also be categorized by how they are disposed of like recyclables, compostables and digestibles.

Who and How Much. The U.S. is one of the largest, most populous, most highly developed countries in the world and nearly every person in the United States produces municipal solid waste. A side effect to these facts is the vast quantity of wastes we as a nation produce. According to the EPA's 2008 report on waste generation; MSW generation that year was 250 million tons. That report also stated that between 1980 and 2008 the average MSW production for every person in the US increased from 3.66 to 4.50 lbs per day.

This waste stream like most others has various components. Some of the major EPA defined categories are represented in the pie graph below with their production percentages in 2008.

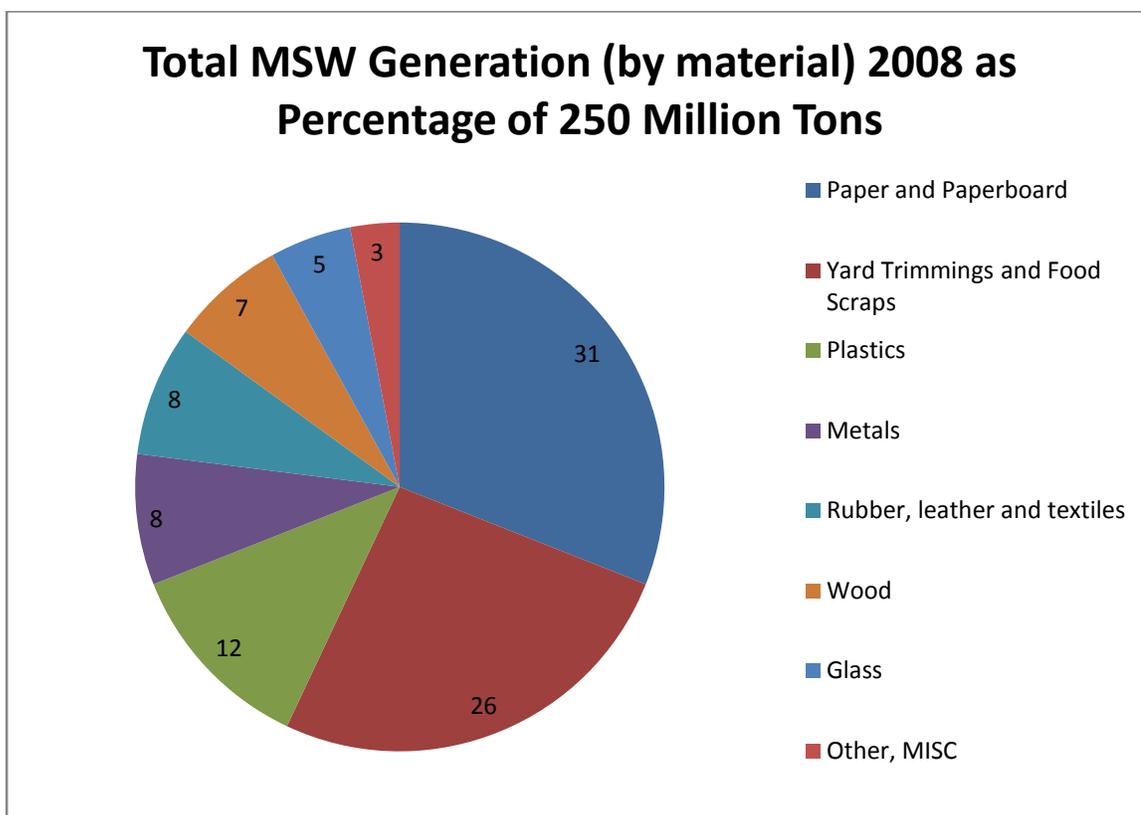


Figure 1. Total Municipal Solid Waste Generation (by material) for 2008 as percentage of 250 million tons total MSW collected (EPA 2008)

NOTE: Totals are prior to recycling at collection sites

Current Disposal Methods. There is a multitude of ways that municipal solid wastes are currently disposed of. The most common method throughout the world is the use of a landfill. Most if not all landfills have the same basic concept; trash is dumped onto or into the ground and left to decompose. Over time the decomposing trash leaves voids below the soil surface and the ground can settle. This would, in theory allow the area to be re-used at a later date. This method allows the concentration of the wastes of large populations into a relatively small area.

There are many types of landfills and they can be separated many different ways. Two very common types are municipal solid waste landfills and hazardous waste landfills. Municipal solid waste landfills take general household, commercial and industrial wastes while hazardous waste landfills handle wastes that require special attention and consideration and therefore are kept separate from other wastes. (Kaniaru, 2002)

Another separation method is the operation and management strategy of the landfill itself. Landfill sites can commonly be further classified as, open dump, controlled dump or sanitary. Although there are many variables the sanitary landfill is generally the most advanced. If the three types were being considered; this type would require the most planning, management and capital to operate in a given location. Open dump landfills are at the opposite end of the spectrum having little or no operation, maintenance or management inputs. Controlled dump landfills fall somewhere in between the other two in these areas. (Kaniaru, 2002)

Another popular method for waste disposal is recycling. Recyclable wastes are separated from general MSW because they can be easily and or economically put to other uses or reformulated to their original use. These wastes are often picked up in the same manner as the other “trash” but usually sent to a facility to be sorted and eventually reformed into something more useful. Different municipalities have different standards that regulate what goes into the recycling container and therefore have different systems for disposing of the waste. Some commonly recycled items are aluminum cans, plastic bottles and paper products.

Biomass

Describe, Define. Biomass like MSW is a natural part of life. It consists of everything from animal carcasses to wood processing wastes like sawdust. Biomass is defined as any material derived from growing organisms. Plant biomass is further defined as material derived from growing plant organisms or phytomass (Hall, 1989). These are very broad terms that include hundreds if not thousands of different items. Due to the very broad nature of this definition waste biomass could consist of many of the same things that could be defined as municipal solid waste. However there are things that are not commonly considered MSW that can be considered biomass.

A few examples of MSW that can be considered biomass are green waste, food industry waste and paper fiber based products like paperboard and cardboard. Some examples of biomass that wouldn't usually find their way into the MSW stream are manure, animal carcasses and waste animal feeds.

For the purposes of this report we are discussing only waste biomass. This would be biomass that was part of something else or that has been changed in some way and is no longer suitable for its original purpose. Manure is considered as its own category and will be discussed later.

Who, Where. Waste biomass is produced by most natural processes at one point or another and by many un-natural ones as well. So many of the MSW streams can be considered to be biomass that we can take the MSW production and apply it to answer how much biomass is produced by individuals and populations as well.

How Much. According to the EPA's 2008 report on waste generation; MSW generation that year was 250 million tons. The report also stated that between 1980 and 2008 the average MSW production for every person in the US increased from 3.66 to 4.50 lbs per day. Referring to Figure 1 we see that biomass made up a large portion of the MSW stream produced in 2008. In fact the two largest portions of the MSW stream can both be considered biomass, paper products and yard wastes. With the addition of wood products this brings the biomass portion to 64% of the MSW stream. This would mean that each person in the US produces approximately 2.88 pounds of biomass per day.

This would not account for the wastes produced commercially, industrially or for components like manure and carcasses. Another significant source of biomass is aquatic life. However, since California has little to no biomass of this type, it was not considered in the report.

Current Disposal Methods. "All organic matter, or biomass, can in one way or another be used as fuel." (White, 1981) As of 1981, "Surprisingly to most people in developed countries about one seventh of the energy used throughout the world at the moment comes from firewood and firewood is the most important fuel for the bulk of the world's population." (White, 1981). While the percentage is undoubtedly different today it's still an important thought.

Biomass has always been an important source of fuel for the world's population but its popularity and usage have been cyclical in nature. Prior to the fuel crisis in the 1980's much of the world's population was on a trend of using cheap, convenient imported fossil fuels. According to White and Plaskett the third world saw an increase in fossil fuel prices of 500% in the 1980's, and this trend increased the usage and interest in continued usage of biomass as an energy source.

The preferred disposal method for biomass really depends on the particular portion of the stream you're interested in. The majority of paper products and yard wastes are diverted from the landfill while most food wastes are land filled. (EPA, MSW 2008). Therefore, the current disposal methods for Biomass are similar to those of MSW. The wastes are generally recycled, composted, land filled or incinerated. Biomass adds

another component to the disposal method discussion however. Wood processing wastes are often turned into paper or other wood products in developed countries while lots of biomass throughout the world is directly combusted to produce heat and or energy for domestic purposes.

Manure

Describe, Define. Manure is one of the many wastes that are produced as a natural part of biological processes. While most people think of manure as waste from livestock animals or pets, it can also be used to describe excrement from the human animal. However, for the purposes of this project manure will be used only to describe the wastes from livestock animals. Manure from the human animal is most commonly mixed with water and centrally collected and processed and will be referred to as one of the components of waste water to be dealt with later.

How Much.

Manure is an important part of many animal agriculture based operations. The quantity, components and disposal techniques are extremely variable. There are marked differences in manure production across many variables in livestock. Manure production, handling, collection and processing all vary with species, operation, and geographic location and can even change with diet and state of health.

Manure Source	Avg. Animal Wt. (lbs)	Feces and Urine Production	
		lbs/day	tons/yr
Beef	800.0	48.5	8.3
Broiler	2.0	0.2	0.0
Dairy	1400.0	122.3	22.3
Duck	3.0	0.3	0.1
Goat	140.0	5.8	1.1
Horse	1000.0	50.3	0.2
Layer	4.0	0.3	0.05
Rabbit	10.0	0.3	0.1
Sheep	60.0	2.4	0.4

Swine	135.0	11.1	1.9
Turkey	15.0	0.7	0.1
Veal	200.0	12.4	2.0

Figure 2. Statistics for Average Animal Weights and Manure Production by Species (Pritchard 2008)

Current Disposal Methods. The primary differences in disposal needs for manure have to do with the housing conditions of each animal species. Although every species has examples to the contrary the following are the generalities of how the different species are primarily housed and how their waste is disposed of.

Dairy Cattle and swine are some of the species which are more likely to be housed “in doors” than others. The housing units vary a great deal in design, size and characteristics but have a few things in common. Generally the ground is concrete and the manure must be removed from the living area. The species that are commonly housed in doors must have the waste removed from their living areas in order to maintain animal comfort and sanitation. This manure can be collected and disposed of in a variety of ways including mechanical scraping and water flushing. After it’s out of the barn it can be handled and disposed of much like other manures.

The species that are commonly housed outside can in some cases need their living areas cleaned up also. This manure is collected and handled in a variety of ways including the trusty shovel and wheel barrow.

Once the manure is collected it’s commonly piled and allowed to decompose or even composted before being spread as fertilizer. The animals that are kept in-doors often have the waste washed from their living areas with water. This water is often kept in an earthen pit or lagoon. This water can be left to evaporate or used to fertilize crops.

Waste Water.

Describe, Define. Waste water is water that has been used and contains some sort of waste. It can commonly be divided into grey water and black water. Commonly, grey water is that water which although unsuitable for consumption, doesn’t contain any biological wastes. Black water, like water directly from the toilet commonly contains biological wastes. For collection purposes on a large scale the grey water, black water and often

water from other industrial or commercial purposes is often mixed in transport and referred to more generally as waste water.

Although technologies to process waste water specifically will not be explored, a brief description of waste water will follow. Waste water is an important part of human waste production and is worth mentioning even if briefly.

Who, Where. All people the world over and most if not all commercial, industrial and residential entities produce wastewater of some sort.

Current Disposal Methods. In urban scenarios waste water is generally sent through large underground pipelines to central locations for processing. In these urban scenarios industrial, commercial and residential waste waters can be kept separate or comingled depending on various environmental conditions and desired outputs. The wastes are processed using different technologies which vary based on quantity and constituents of the water.

The process can be very simple or very complex and in general the expenses are directly positively related to the quantity and concentration of the wastes being processed. In general the water is run across a screen to remove solids, settled over time to remove smaller solids and treated biologically to remove the smallest of biological components. The treatment can be taken further with reverse osmosis or similarly intensive processes but this generally comes at great input cost.

These facilities can process the water to be acceptable for human consumption but more commonly the water is processed to a slightly lower standard of quality and used for a non direct consumption purposes. The other major output from the treatment process is the solid waste or sludge which can be spread on non food crops but is sometimes inadvertently contaminated by toxic chemicals requiring special handling and disposal.

In rural scenarios waste water is commonly collected in underground septic tanks and allowed to decompose naturally. These tanks are sealed storage tanks that give the waste time and space to decompose using natural processes. These tanks keep the waste from public view and more importantly, smell.

The above processes are those commonly used in the developed nations of the world and are those that would apply to the Cal Poly S.L.O. campus. There are millions of people around the world that handle wastes in a

more primitive fashion. Many of these people don't have the luxury of toilets, let alone plumbing.

Alternative Waste Handling Technologies

Microbiological Processes. Research is being done into many possibilities for microbiological conversions of biomass. Single cell proteins could be grown from biomass and the biomass handbook discusses how this was considered as a possible alternative to animal proteins. Other alternatives are use for biomass in the production of yeast, bacteria, fungi and algae. (Kitani, 1989)

Another important possibility is ethanol production from biomass. This would generally be a result of fermentation which is discussed below. Fermentation can also be used to produce acetone and butanol.

Thermal Processes. These processes convert biomass into useful fuels via heat treatment. There are numerous types and most of the types have multiple variations that make them specifically suited to a particular application. Some application variables are the quantity and composition of the inputs as well as the composition, quantity of the desired outputs.

Direct Combustion or Incineration. "Combustion of biomass may be classified as either the direct combustion of solid biomass or the combustion of oils, liquids, and gases synthesized from biomass" (Kitani, 1989). For the purposes of this paper direct combustion will be considered to be the former. This is very commonly encountered even today and is best exemplified by burning wood or other high carbon materials for domestic needs.

This technique is used the world over by millions of people throughout the year. Although from a purely academic view it is relatively efficient since there are no conversion losses it is undesirable on a large scale for a number of reasons. When used primarily for heat production this technique is relatively inefficient because of the amount of resources necessary to produce a given amount of heat. Also, it often produces copious amounts of unwanted pollutants.

On a larger scale there are problems to be overcome before direct combustion could be used as an alternative to current use of landfills. Direct combustion of biomass would require prior processing, handling

and collection; all of which require capital inputs. Furthermore, high moisture and low energy density values can make it uneconomical. Lastly and possibly most important in certain locations, copious amounts of energy could be required to sustain the reaction and large amounts of unwanted pollutants and other outputs could be produced.

Apparatus for direct combustion range from simple open pits to fully automated large scale furnaces. Devices are available to handle most forms of biomass. (Kitani, 1989)

Gasification. Gasification is defined as to make or become a gas. (Webster, 1988) In practice it is a thermal process used to convert high carbon materials, like manure, MSW and biomass into gasses. The process produces carbon monoxide and hydrogen. Gasification takes place when carbonaceous materials are reacted at high temperatures with steam, air or oxygen. The products of the reaction are the gasses mentioned above, commonly called synthesis gas or syngas. This syngas can be combusted or chemically converted to electricity.

There are hundreds of different variations of how this process can take place. Some variables are reaction temperature, reaction conditions, heat conduction material and mixing shaft orientation. There are even processes that don't use a mixing shaft but a column of air to keep the reaction materials in motion.

Three main processes may be distinguished: air gasification, which yields low energy gases, oxygen gasification which produces synthesis gas, used for methanol production and hydrogen gasification used for the production of synthetic natural gas or methane. (Reed 1981)

The feedstock for gasification is usually wood although cellulosic inputs such as cereal residues may also be used. These should ordinarily be dry but oxygen gasification can utilize wetter materials and will yield more synthesis gas as a result.

Plasma Arc Waste Disposal. Plasma arc waste disposal is a form of gasification. This process sends an air stream through the high voltage, high amperage electrical arc produced by two separated electrodes. The air stream is sent into a container that houses the material to be gasified. In the case of MSW gasification where a conventional plant produces about 685kWh per ton of MSW this process produces approximately 816 kWh from the same ton of material.

This process operates at very high temperatures and produces syngas and a rock like by-product or slag. The syngas can be converted to electricity

or combusted for other purposes. The slag can be used to produce other byproducts such as rock wool, floor tiles, roof tiles insulation and landscaping blocks. The process is extremely capital intensive. (Young, 2008)

Pyrolysis. Pyrolysis is the name of an important stage in all gasification and combustion processes for both coal and biomass. It is also defined as the destructive decomposition of biomass using mainly heat to produce char, oil and medium BTU gas. (Kitani, 1989)

Pyrolysis has been researched as its own technique for waste conversion considered uneconomical. The process is less tested than gasification but can be optimized in order to produce mainly solids or liquids depending on many variables. There are four main process types. The first process is incomplete combustion which is starved of oxygen. The next is pure pyrolysis, which uses no oxygen, the third is indirect liquefaction and the last process type is direct liquefaction. (Hickman et al, 1984)

The advantages of using gasification or pyrolysis are that the resulting fuels have greater ease of transport and distribution than the original inputs. Gases are more desirable than solid fuels. There is also a greater ability to meter the conversion in a controlled manner into combustion chambers via automated equipment. This relates to an increased effectiveness in electricity generation. Two more important advantages are a lack of ash and suitability for fueling transport. (Reed, 1981)

Other Thermal Processes. There are some other noteworthy forms of thermal waste disposal. Refuse Derived Fuel or R.D.F. is waste that has been processed before being treated thermally. This waste is shredded to create uniform size particles of combustible materials, those being composed of cellulose and organics, all others are separated before combustion. This process can be performed on MSW and biomass as one of its components. Furthermore this process can be followed by another physical alteration like being compressed, extruded or made into pellets. These steps would be used in order to dehydrate; more precisely size or otherwise improve the efficiency of using these products for combustion. (Hickman et al 1984)

Biological Processes.

Aerobic Decomposition. Aerobic decomposition has been the traditional method for disposing of waste for hundreds of years. When wastes are piled they start into the aerobic process but the free air toward the center of the pile is generally used up rapidly. This leads to an anaerobic condition and anaerobic decomposition which will be discussed later. However, if the pile is turned the aerobic process continues and the wastes can turn into compost depending on their composition. This is not typically used for energy production. The outputs however are still generally much more desirable than the inputs.

Composting. Composting is currently practiced throughout the world including on the Cal Poly campus. There are various methods including a hand turned pile in a backyard to enormous constant production industrial operations. Many materials can be composted separately but more commonly materials are combined in order to provide a more desirable starting product. As with any biological process the bacteria involved operate best within certain parameter ranges. Some important parameters are moisture, viscosity, density, porosity and toxicity. For example chicken manure and bark will both compost separately but when combined the process is faster and therefore more efficient.

The end product of composting is very environmentally friendly and can be used by the proprietor of the operation as in the backyard example or can be marketed and sold to the general public as in the large scale industrial example.

The input materials can be anything from biological waste to wood pulp. These components are often processed prior to being composted in large operations. Similar moisture content, particle size, density and other factors will allow for increased efficiency through increased control. (Kitani, 1989)

Anaerobic Digestion.

Basics. Anaerobic digestion is a biological process that takes place in the absence of oxygen. This process converts and stabilizes organic materials to methane and inorganic compounds through a multistage bacterial interaction. These digesters can take many forms. In nature they commonly occur in swamps; while man-made versions can be a covered manure lagoon or a series of tanks filled with organic matter. In the man-made versions the waste material is added, usually at one end of the system to facilitate better system control. The waste is in the anaerobic environment for a certain amount of time called retention time. Three

major bacterial steps take place and the waste material is converted to CO₂ and various other components. (McCarty, 1982)

There are a few real values to an anaerobic digestion system. Digesters produce bio gas and digestate. These products can both be a source of income to the operator of the system. The methane can be used as a source of electrical or heat energy and the digestate can be used as a field additive or sold.

The other major benefits are environmental, in the case of manure storage ponds the anaerobic digestion process is occurring naturally. If it is left unchecked the methane produced bleeds off into the atmosphere. If this methane is collected and converted to heat or electrical energy the waste product is most often CO₂ which is less damaging to the environment than methane. (Krich et al 2005)

Fermentation. The fermentation of biomass to ethanol has been used for beverage production for over 10 000 years. Traditional fermentation utilizes feedstocks with naturally high sugar contents or which contain easily hydrolysable carbohydrates such as the starch in grain. Fuel alcohol production uses essentially similar processes to those used for beverage production but optimizes quantity rather than quality of production. (Kitani, 1989)

The production of fuel grade ethanol, generally 95% pure involves three stages. First the feedstock is processed to produce a sugar solution. Fermentation then utilizes microorganisms, normally yeasts to convert the sugars to ethanol. The product is a dilute beer usually less than 9 % ethanol by weight, which must then undergo energy intensive distillation to remove the water.

Fermentation may be operated at the farm scale or in industrial scale plants with significantly higher outputs. A variety of fermentation systems have been developed based on batch or continuous processes. Improvements in fermentation are being sought in four main areas: increasing ethanol productivity, improving sugar conversion efficiency, increasing the ethanol content in the beer and development of simpler and cheaper processes. There is also considerable research on distillation with the development of a number of techniques aimed at reducing the energy requirements of this stage.

Problems with fermentation are that feedstocks ideal for fermentation are usually reserved for more profitable alternative uses. Most waste products are not ideal to be fermented. However due to the energy potential of the process outputs interest in the process is increasing.

Another possibility is the fermentation of biomass to produce acetone and butanol. These chemicals have various industrial uses. Although this is possible, the economics don't currently support this on a large scale, primarily due to the relatively low cost of petrochemicals (Kitani, 1989)

Mechanical Processes.

Ocean Dumping. Ocean dumping is a practice of waste disposal that was traditionally used in by urban populations that were close in proximity to water. It is still currently being used in some areas, especially those with less developed or environmentally conscious waste disposal systems.

The old saying is, "The solution to pollution is dilution." The problem is that with an ever increasing population the concentration of the wastes being dumped is increasing also.

The ocean has been the dump site for many of society's waste streams, biomass, MSW, manure and biological wastes. In fact some waste water treatment facilities currently operating in the U.S. dump the output of their facilities miles offshore. (Bono, 2008)

PROCEDURES AND METHODS

Research Procedure. Research for the paper was gathered in many forms. By far the bulk of the research was done through published works dealing with biomass and biomass conversion processes. There were however many other methods that were utilized. They included but were not limited to:

1. Literature Based Research
2. Personal Communication and Interviews
3. Reviews of Periodicals and Websites
4. Review of Projects Produced by other Cal Poly Students

Data Collection. Data was collected from a number of sources. These included past projects and personal contacts with different members of the Cal Poly campus community who are involved in waste collection. Some of the contacted persons included

1. Richard Bono, Superintendent of the Tulare Waste Water Treatment Plant
2. Mr. Kevin Shaw Facility Services Warehouse Operations Manager

RESULTS

Waste Composition and Production at Cal Poly

General Information. Cal Poly is a diverse and constantly changing campus. The population on the campus is in constant flux. In 2005 the total faculty headcount was 1,246; but it varied from 964 in the fall of 1994 to 1,246 in the fall of 2002. In 2005 the number of students enrolled varied from 2,102 in the summer to 17,286 in the fall. (Cal Poly Fact Book 2008) This would add to approximately 18,000 people on Cal Poly's campus daily.

Using the EPA calculated waste generation of 4.6 pounds per person per day Cal Poly's campus produces approximately 25,000 pounds of garbage every day. Cal Poly disposes of this waste using traditional methods but also uses composting and recycling. However the campus currently does not have any large scale energy generating form of waste conversion. Such a system could have the potential to be of great benefit to the faculty, staff, the community and the environment.

Cal Poly Waste Generation 2007-2008					
Waste	Amount	Units	Pounds	% of Total	Disposal Method
Green Waste	72.44	tons	144,880.00	1.40	Composted
Food Scrap	1500-1800	lbs/day	79,200.00	0.77	Composted
Compost	47,600.00	cubic yards			Used in Landscaping
Metal Waste	99,451.00	lbs	99,451.00	0.96	Recycled/ Pacific Industrial
Ink Cartridges	123.00	lbs	123.00	0.00	Recycled
Cardboard	90.98	tons	181,960.00	1.76	Recycled
Textbooks	50.16	tons	100,320.00	0.97	Recycled
Used Oil	323.00	gallons			Recycled
E-Waste	n/a	n/a			Auction/ Recycle
Auction	88.00	tons diverted	176,000.00	1.71	MERF/Recycled
Misc Recycling	473.00	tons			MERF
Dairy Sewage	4,000.00	tons	8,000,000.00	77.58	Crop Applied
Asphalt and Concrete	289.00	tons	578,000.00	5.60	Crushed/Reused
Tallow	225.00	lbs/week	10,800.00	0.10	Rendering Plant
Construction Debris	389.00	tons	778,000.00	7.54	Landfilled
Shredded Paper	25.50	tons	51,000.00	0.49	Landfilled
Mattresses	20.00	tons	40,000.00	0.39	Landfilled
Tires	36.40	tons	72,800.00	0.71	Landfilled
Antifreeze	69.00	gallons			Hazardous Waste
Total			10,312,534.00	100.00	
This Waste was collected over the course of 48 weeks or 336 days					

Table 1. Actual Waste Generated on Cal Poly's Campus for 2007- 2008.

Municipal Solid Waste. For the purposes of this report M.S.W. will consist of the wastes categorized as: Metal Wastes, Ink Cartridges, Cardboard, Textbooks, Miscellaneous Recycling, Asphalt and Concrete, Construction Debris, Shredded Paper, Mattresses, and Tires.

Who, Where. These waste materials were collected from all over the campus. There were multiple construction projects undertaken over the course of the collection period.

How Much. These wastes make up approximately 20 percent of the total wastes collected or about 2 million pounds of waste.

Current Disposal Methods. The waste disposal methods vary but most of the waste is recycled, while some is sent to the local landfill.

Possible Disposal Methods. Depending largely on the construction of the unit and variables concerning the system design all of these materials could be disposed of using one of the thermal processes.

Manure. Although some of the manure produced on campus is collected for use in the composting process this isn't true in all cases. The manure production numbers presented below are based on possible maximums in animal units in each area, national averages for animal manure production and a general percentage of possible collection based on personal experience.

Who, Where. Manure is produced in multiple locations across campus. There are different locations that are designed to house specific animals in a manner consistent with that of current industry practice. The different areas are called animal units, meaning areas of animal housing units. The different units are dairy, beef, horse, swine, poultry and sheep.

How Much. The maximum possible amount of manure that could be produced across campus is approximately 17,000 lbs. This would be given optimum conditions. These conditions would be each animal unit housing

its maximum number of animals and each animal producing the national average amount of waste for its type. This doesn't account for smaller or younger than average animals.

Current Disposal Methods. Currently most manure is composted while some is left to decompose naturally where it is produced.

Possible Disposal Methods. All manure produced on campus could be processed using the thermal or biological processes discussed previously. The feasibility of this processing would depend greatly on how the waste is managed prior to conversion and how the conversion process is designed.

Biomass.

Who, Where. There are multiple locations where food is served and disposed of across campus. The most notable location for food scrap waste is dining services where the majority of the food served on campus is delivered, stored and processed prior to distribution. Other major areas are satellite food preparation area like campus market and the burrito bar near Dexter lawn.

How Much. Approximately 79,000 lbs of biomass are produced and collected yearly. This would be approximately 1% of the campus waste stream.

Current Disposal Methods. Currently most biomass is composted while some is discarded to the local landfill.

Possible Disposal Methods. All biomass produced on campus could be processed using the thermal or biological processes discussed previously. The feasibility of this processing would depend greatly on how the waste is managed prior to conversion and how the conversion process is designed.

Waste Water. The waste water produced on campus isn't monitored or collected prior to arrival at the SLO Municipal Waste Water Treatment Plant. This plant doesn't monitor campus production separately from other sources and therefore no accurate production data is available.

Who, Where. Waste water is produced literally in every building on campus. The purposes of the buildings on campus are to house students in order to serve them in their goal of obtaining an education. This means every building on campus will at one time or another house students. These students all produce biological wastes, which are almost always disposed of through the campus waste water handling systems. However there are some areas where production would be more concentrated than others, these would be dormitories and other areas of consistently high traffic.

Current Disposal Methods. Currently the waste water from campus is disposed of through the city's common sewer system.

Possible Disposal Methods. The waste water from campus could be processed any number of different ways as seen in industrial practice today, none of which were researched or will be discussed due to the inherent dangers.

Special Needs Wastes. These are wastes that are generally considered hazardous. The wastes that were disposed of on campus that would qualify are: Antifreeze, Waste Oil, E-Waste and Tires.

Who, Where. The majority of the automotive based wastes are produced in two places. The state warehouse where state equipment is repaired and the farm shop where farm machinery and vehicles are repaired. The electronic waste is produced from all the offices on campus as things like computers, monitors and printers need replacing.

How Much. These wastes account for about 1% of the total collected on campus or just over 80,000 pounds of waste.

Current Disposal Methods. These items are generally sent to an auction if they are useable so that some money can be recouped. If they are broken or otherwise unsellable then they are discarded. Due to the special materials involved in manufacturing some of these components they are considered a hazardous but very recyclable waste stream.

Possible Disposal Methods. Although most of these wastes could be sent through some sort of energy recovery facility; due to their high value in recyclable parts they are generally recycled through state wide programs.

Alternative Waste Handling Technologies for Cal Poly

Thermal Processes

In theory any of the above listed thermal processes could be used to dispose of Cal Poly's waste streams.

The most appropriate thermal process was determined to be a form of gasification. Gasification is widely studied and has hundreds of different possible process designs. Gasification is ideal for Cal Poly because of the tremendous system design flexibility and the amount of previous research done on the viability of certain systems in certain situations. The specifics of the system would largely be governed by variables not studied here, which include energy usage, space requirements, environmental regulations, and desired outputs based on possible usages.

Biological Processes

Any of the above listed biological processes could be put into use at Cal Poly SLO. Aerobic digestion in fact is currently being used as a natural part of life. Anaerobic digestion is currently in use in parts of the manure lagoons on campus as well.

Anaerobic digestion was chosen as the most feasible alternative waste disposal and conversion technique. Composting is also a very good use of campus waste but isn't truly an alternative since it's currently used on campus. Once again many outside factors would have to be considered before a true determination could be made but this showed the most

promise. Anaerobic digestion shows promise for a number of reasons. Firstly, a system was previously used on campus at the dairy and some of the equipment is still in place. Secondly, there is much industry support for use, study and experimentation of the technique and its associated technologies. Furthermore, this process is currently used in many aspects of commercial and industrial waste disposal. Also, this would allow the disposal of the majority of wastes generated on campus especially manure and food wastes. However, many of the specifics of the process' design would depend on outside factors like environmental regulations and actual industry support.

Mechanical Processes

General Description. The majority of alternative mechanical processes that could be used to dispose of campus wastes are considered inappropriate. Most of the other mechanical processes discussed previously do not produce a more desirable end product than the processes currently used on campus.

Cal Poly Waste Generation 2007-2008				
Waste	Amount	Units	Pounds	Possible Disposal Methods
Green Waste	72.44	tons	144,880.00	Direct Combustion, Gasification, Pyrolysis, Anaerobic Digestion,
Food Scrap Compost	1500-1800	lbs/day	79,200.00	
Compost	47,600.00	cubic yards		
Metal Waste	99,451.00	lbs	99,451.00	
Ink Cartridges	123.00	lbs	123.00	
Cardboard	90.98	tons	181,960.00	Direct Combustion, Gasification, Pyrolysis
Textbooks	50.16	tons	100,320.00	
Used Oil	323.00	gallons		Direct Combustion, Gasification, Pyrolysis
E-Waste	??	???		
Auction	88.00	tons diverted	176,000.00	
Misc Recycling	473.00	tons		
Dairy Sewage	4,000.00	tons	8,000,000.00	Anaerobic Digestion
Asphalt and Concrete	289.00	tons	578,000.00	
Tallow	225.00	lbs/week	10,800.00	Direct Combustion, Gasification, Pyrolysis
Construction Debris	389.00	tons	778,000.00	Direct Combustion, Gasification, Pyrolysis
Shredded Paper	25.50	tons	51,000.00	Direct Combustion, Gasification, Pyrolysis, Anaerobic Digestion
Mattresses	20.00	tons	40,000.00	Direct Combustion, Gasification, Pyrolysis
Tires	36.40	tons	72,800.00	Direct Combustion, Gasification, Pyrolysis
Antifreeze	69.00	gallons		

Table 2. Waste Generated and Possible Disposal Methods

DISCUSSION

Waste Composition and Production at Cal Poly

The wastes produced at Cal Poly are what one would expect from a university of its size and diversity. Due to the complexities of the Universities inner working it's not apparent if all wastes were accounted for by the sources of the collection information. The presented information is however valuable and relevant as the waste collection, monitoring and disposal is a major part of the regular duties of a few individuals that were contacted.

Alternative Waste Handling Technologies for Cal Poly

Thermal Processes. The thermal process that seemed to be the most feasible at cal poly was gasification. It is assumed that due to the current financial and higher education climates in California that Cal Poly SLO itself could not afford to implement and sustain a program for using and testing an alternative waste management technology. Gasification was seen to be the most likely candidate for an on campus alternative to waste disposal for a few reasons.

First is industry support. Gasification is well studied and the extreme variability in possible inputs and outputs would lend well to testing and could allow the campus to make use of various wastes.

The appropriate process is difficult to determine due to the number of outside influences that would affect the decision. For example even if pyrolysis was chosen as the most viable alternative in terms of strictly converting waste, if the only outside funding available was for a large scale plasma arc waste disposal facility this would most likely be the process chosen.

Biological Processes. The biological process and technology set with the most promise is anaerobic digestion. Again it is assumed that cal poly could not afford to sustain a program in this area. However anaerobic digestion has large amounts of industry support and is still in the testing phase in many ways. Although there are large industrial scale plants in different parts of the world it is especially difficult for business people in CA to use this technology economically. The pollution caused by the

different gas conversion methods and perceived pollution from the earthen lagoons commonly used to house the reaction are both a cause for concern.

Never the less the process is effective and can always benefit from further testing in order to increase efficiency or efficacy. The process also has benefits in creating electricity and waste heat, both of which can be used on campus.

Lastly economic benefits can be obtained in real study from mixing the influents into the digester. If community wastes from various sources were added to the digester gas production and positive economics could be increased. Testing this on a small scale could lead to this being an accepted practice in places where it isn't currently used.

Mechanical Processes. The current state of Cal Poly's MSW handling is admirable considering almost 60 percent of the total campus-wide solid waste tonnage is recycled or otherwise diverted from the landfill. Numerous measures have been instituted for different types of waste. Therefore there were no recommendations made as another physical technology to be used in getting rid of waste. Recycling, composting and reselling are all valid ways to cut down on waste entering local landfills.

Research Procedure. By far the two most useful forms of research were personal contact and literature on biomass and biomass conversion processes.

Data Collection. Data was collected from a number of sources. These included past projects and personal contacts with different members of the Cal Poly campus community who are involved in waste collection.

Feasibility Determination. As previously stated Mr. Richard Bono, superintendent of the Tulare waste water treatment plant was especially helpful during the course of the project. Over the past twenty years the plant he supervises has undergone various changes and upgrades in technology. The plant currently used anaerobic digestion and converts the waste gasses to electricity using fuel cells. Despite the benefits of the system without government subsidy, city investment and outside funding the project would not have been possible. This project was implemented before the current economic downturn and is a major source of economic and political contention. It was determined that now would not be the time for such a project on Cal Poly's campus due to the simple lack of funding.

Although much good could come from such a project it was determined that until the economy turns around donations to undertake such a project, or any other capital intensive waste management change would most likely not take place on campus.

RECOMMEDATIONS

General Recommendations

The general recommendations for the campus at this time are to stay the course. Despite the tremendous amount of waste produced on campus, the university and its community do a tremendous job of handling the wastes produced while staying green. A large percentage of campus wastes are currently diverted from landfills and the work is to be commended.

Alternative Waste Handling Technologies for Cal Poly

Many possible alternatives to Cal Poly's current waste management system were considered. Although many of the technologies seemed promising two seemed most useful. The recommendation for further technological research would be to re-implement the anaerobic digester that was on the Cal Poly Dairy and or to install and operate for research purposes a gasification system.

The anaerobic digestion system could make use of the micro turbine left over from the previous system. However it might be more useful to obtain, probably through donation or a loaner program some fuel cells to test their real world feasibility with animal wastes.

Further Research

This project and the university as a whole could derive much benefit from further and more in depth research into this area. There are many technologies that seemed promising and many waste streams that seemed useable but the current state of many of these factors is constantly changing. Regulations at the local, regional, state and federal level could change at any time to make the any of these technologies more or less feasible.

Industry Support

In order for a system like those researched to be implemented on campus industry support is needed. With proper development a presentation with campus support could well drum up such funding. This would be of great benefit to everyone involved. This is also another possible source of work for future students, possibly in a marketing or business class of some sort.

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APPENDIX A

HOW PROJECT MEETS REQUIREMENTS FOR ASM MAJOR

HOW THE PROJECT MEETS REQUIREMENTS FOR THE ASM MAJOR

ASM Project Requirements

Senior projects for students in the Agricultural Systems Management major must include a problem solving experience that incorporates the application of technology and the organizational skills of business and management and quantitative, analytical problem solving. The project fulfills these requirements as follows.

Application of Agricultural Technology. The purpose of this project is the identification and comparison of technologies for waste conversion. These technologies use systems and technology that are used in agriculture and other industries. Waste is mechanically collected, transported and biologically, mechanically or chemically converted. Agriculture uses many of these technologies in various applications.

Organizational Skills of Business and Management. This project incorporates research, data collection and concludes with evaluation of technologies. Every business must evaluate the balance of positive and negative attributes of techniques and technologies in order to make informed managerial decisions. The information should be well prepared, organized and conclusions should be sound and hold merit in order to present the information in a format consistent with sound business practices.

Quantitative, Analytical Problem Solving. This project uses quantitative as well as qualitative values to draw conclusions about feasibility. The project will analyze alternatives and present possible solutions to the various problems associated with Cal Poly's current waste management and disposal system.

Capstone Project Experience.

The ASM major must incorporate knowledge and skills acquired in earlier coursework (Major, Support and/or GE courses)

- BRAE 142 Agricultural Power and Machinery
- BRAE 321 Agricultural Safety
- BRAE 343 Mechanical Systems Analysis
- BRAE 348 Energy for a Sustainable Society
- AGB 212 Agricultural Economics
- AGB 310 Agribusiness Credit and Finance
- DSCI 101 Dairy Feeds and Feeding
- DSCI 121 Elements of Dairying
- DSCI 301 Dairy Cattle Nutrition
- DSCI 470 Special Problems: Manure Collection and Treatment
- ENGL 418 Technical Writing

ASM Approach

Agricultural System Management involves the development of solutions to technological, business or management problems associated with agricultural or related industries. A systems approach, interdisciplinary experience and agricultural training in specialized areas are common features of this type of project.

Systems Approach. Waste management, waste disposal, anaerobic digestion and all its alternatives are all systems, social, mechanical or biological in nature. These systems include biological, mechanical, electrical, social, environmental, economical, and various other types of components. In order to be successful in managing the waste on a campus of this size or to analyze that management a use, knowledge and understanding of systems is necessary.

Interdisciplinary Features. This project incorporates coursework from multiple disciplines, collected information and various skills in order to adequately evaluate the feasibility of using alternative technologies to dispose of Cal Poly's waste.

Specialized Knowledge. This project incorporates specialized knowledge in the evaluation and comparison of the discussed systems. An understanding of waste management and special constraints is necessary to evaluate the technologies for use