# LIFE CYCLE BALANCING WATER/W.WATER SYSTEM

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# LIFE CYCLE BALANCING/WATER/WASTEWATER

## INITIAL COMPARISON OF ALTERNATIVE WASTEWATER TREATMENT SYSTEMS

### BACKGROUND AND PURPOSE

More than 1 billion dollars worth of energy per year is used by conventional sewage treatment processes in the United States. Conventional wastewater treatment technologies spend millions of dollars ridding their facilities of the "left over" yet valuable sludge. These two factors exclude the fact that waste water facilities rank approximately 10th of all industrial processes in the U.S. as to their embodied environmental impacts, e.g., the materials that are needed to produce the thousands of miles of pipe, containers and other equipment. These numbers do not include the operating costs and impacts of these facilities on the total greenhouse gases produced by humans. When considering the entire life cycle of wastewater treatment, this sector could be one of the higher environmental burdens. Despite the fact that "alternative" systems usually concentrate on replacing mechanical systems with plant systems and reducing the amount of energy used, beyond this there is usually no stated goal of ultimate material balance or reuse of waste for productive purposes. The NBSB has an important statement it can make in this area and, as one will find, provide an exquisite venue for expressing the beauty and intricacy of working with the landscape components of this building to neutralize environmental impact.

Life cycle design is very important when placing into perspective the wide range of alternative waste water systems now recognized within the sanitation field. How any process links to other processes, once a performance goal is set, determines whether or not any particular waste water system is relevant. For example, if our purpose is to reduce the treatment area footprint in an urban setting, this creates one set of ramifications on our choice of systems. However, if our purpose is to balance carbon within the wastewater treatment life cycle on site, this might dictate another set of options. In fact, as this analysis begins to show, these two topics could have diametrically opposing solutions. A pattern seems to exist where systems of smaller footprints produce more CO2 due to the fact that there is a greater reliance on mechanical than biological systems sequestering or the uptake of carbon may not be maximized.

Life cycle design also dictates that we always consider and complete full cycles in the design of all processes whenever possible. Depending on one's purpose, the life cycle of the water/ waste water sequence might start with waste as a source, or waste processing might be placed at the end (re-source stage) of the water cycle. Alternatively, the life cycle sequence could start with the collection of precipitation as the source of the entire cycle if we were to balance all material upstream impacts of the system. The importance of working with this simple differentiation points towards how one is conceiving the design of the system and the overall goal that has been set. For example, a very tightly knit water/wastewater cycle could use a totally physical / chemical treatment of water and immediately use this treated water as the source of input water that normally would use fresh water. This would enable water and wastewater to more or less be continuously cycled (minus system losses) and drastically cut down on total water use and perhaps the footprint needed for treatment overall. On the other hand, this skirting or purposely skipping the need for any natural processes (e.g. the use of plant matter to do part of our processing work) may also skip the critical issue of CO2 balancing within the system. Other similar issues can be looked at regarding how we critique natural systems because although some systems do sequester carbon, they accomplish this on such a quick seasonal basis that only the growth and decay of plants themselves are CO2 balanced (e.g. perennial plant species). Another key issue in critiquing natural systems treatment is the fact that some systems can easily become anaerobic and become sources for methane which is per volume 21 times more serious than CO2 in creating greenhouse gases. Therefore, it is important that we identify these overall system issues if we are going to seriously address global environmental impact.

The purpose of this analysis is to introduce these factors and also, in a more basic sense, to bring to the attention of the client and the A & E's what alternatives exist. In this way we might suggest that physical (dimensional) footprint reduction verses chemical (CO2) footprint reduction or both is possible and can be cost effective. The latter will be taken up by the Sackett/Stretch full cost accountants at a preliminary level during the January session. The overall team will recognize in the Sustainable Design Group's report on hydroxly waste water treatment (a potential CO2 augmenter but physical footprint reducer) that financing this package unit might be a good deal more easily accomplished than financing natural systems (a potential CO2 sequesterer). This is unless the money saved in leasing the packaged hydroxly unit can be used to create other long term and/or combined strategies on and off site for greenhouse gas removal.

It should be noted that solutions for all the above problems e.g. physical footprint, CO2, methane, etc. can only be addressed at a precursory level at this time. Wastewater treatment systems in addition to the Todd system (Patkau 11/9/98) being reviewed in this analysis are the following:

Primary systems

1) Anaerobic digestion (wastewater lagoons),
2) Anaerobic digestion (attached film bed)
3) Methane (biogas generators)
4) Super oxidation

Secondary systems

5) Aerobic Biomass (Forest Mantle)
6) Aerobic (Wetland Systems)
7) Windgrow
8) Vermiculture

## TYPICAL WATER/WASTEWATER BASELINE

In order to fully understand the baseline upstream life cycle impact that water and wastewater components produce in the generic sense for this building type and size, please refer to the report entitled Upstream Electricity Water and Sewer Environmental Impacts – January Report by Norris under sub-contract with the CMPBS. The report cited outlines what areas of environmental impact would have to be compensated for once we choose an alternative system if we were to improve the overall condition of water wastewater treatment. It is our understanding that these issues will be discussed at the January meeting in Houston once we have decided on all building systems and subsystems in general.

### ANAEROBIC TREATMENT

Anaerobic treatment for this report is divided into two types of systems 1) Lagoon Systems (which are combined anaerobic and aerobic treatment systems together into the same system and 2) the Attached Film Bed approach developed by Cornell University. Both systems are explained because they offer different types of urban possibilities (mainly lagoons) involving a larger footprint and can be worked effectively into an urban landscape with water features that may be a better fit on to the adjacent 100-acre land area. The second system is also explained due to its smaller footprint but more mechanical approach fitting on site. It is believed that both systems can achieve $CO_2$ balancing but further expertise would have to be consulted in order to establish the technical and economic feasibility.

1) THE LAGOON SYSTEM

Lagoons are one of the oldest wastewater treatment systems known and therefore have not only a long history of use but also require the least degree of mechanical equipment. Due to the fact that they are primarily made up of a pond or ponds, they have been successfully integrated into park and recreation areas. These areas can aesthetically absorb the lagoon system's relatively large physical footprint within the landscape, with a progression from no human contact (just visual connection) at the first pond to boating and fishing at the latter stages of retention.

The process involves the use of bacteria and algae. The bacteria digest and oxidize the sewage while the algae, through photosynthesis, produce oxygen required for aerobic bacterial action. As a USAID manual states, "the oxygen cycle of decomposition is complete and continuous, as oxidation forms carbon dioxide, this carbon dioxide is used by the algae, resulting (in certain conditions) in the creation of additional oxygen". This report goes on to state that "anaerobic action creates ammonia (a nitrogen compound) which is in turn stabilized by oxidation through aerobic action – the result being a natural cycle achieving stability without the creation of offensive conditions."

Problems with the system occur in colder regions where photosynthesis processes cannot balance the input of waste. However, this problem is limited to northern latitudes. The issue of algae blooms should only occur in particular stages and be controllable, and if accomplished properly, can add to the general aesthetics in a marsh type environment and become part of the pedagogical process. The issue of solids build-up in the bottom of the pond requires some periodic cleaning, but this occurs very slowly (1-3.5 inches/year). This usually allows 10-15 continuous years with little or no removal or maintenance. However, many codes state that due to some unpredictability in the operation of the system caused by weather, anaerobic conditions producing hydrogen sulfide can occur. Therefore, it is advisable to place the ponds at least 1/4 mile from densely populated areas, restricting the use of the system to a park-like environment within the 100-acre track. (It is advisable to reconsider whether current practices with well-engineered lagoons already existing in city parks have been able to get around this problem). Fortunately or unfortunately, the resulting wastewater product does not fit state code requirements. This is fortunate because the system needs to have the wastewater irrigated onto plants, which can become an effective way of producing biomass and establishing the necessary carbon sink to balance any unbalanced $CO_2$ problems. (See Forest Mantle System). The problem of methane production has not yet been addressed in this analysis.

FOOTPRINT

The physical footprint ranges anywhere from 100-200 persons per acre for the older systems to 600-1200 persons per square acre of pond for the newer, better-engineered approaches. The forest plan area needed for balancing carbon dioxide must be researched further.

2) ATTACHED FILM BED SYSTEM

This approach was primarily developed to enable anaerobic digestion occur more efficiently, more predictably and while retaining the potential for capturing the CO2 and methane. However, this system would require a dedicated greenhouse for using the CO2 and a means for capturing and using the methane. The only other means is to balance these issues with the growth of plants either by means of the Forest Mantle system or through the hydroponic biomass approach (e.g. wetland system).

The technique is based on the simple premise of enlarging the surface area for anaerobic bacteria to grow on, thus increasing the efficiency. Researchers at Cornell, where the system is being tested, call this "microbial film attachment" that occurs on the carefully chosen small inert particles onto which the film is attached. The technique enables bacteria mass to be 100 to 1000 times that of other systems per volume of area as compared, for example, to the lagoon system). This high density almost negates any weather-related system operation problems.

FOOTPRINT

It is difficult to translate figures as they stand to an actual physical or chemical footprint, but this will be accomplished by the January meeting.

3)METHANE (BIOGAS) GENERATORS

Anaerobic systems generate significant amounts of biogas, which is roughly 60-70% methane, 30-40% carbon dioxide and less than 1% hydrogen sulfide. Methane is considered 21 times worse relative to global warming than is CO2. The advantage of a concentrated system od methane production however, is the fact that it can be captured and used as a fuel. Biogas production is proportionate to the BOD (concentration of organic material) of the wastewater. When biogas is utilized as a fuel source it can be "scrubbed" of the carbon dioxide and other gases to purify and capture the methane.

Biogas technologies have been pioneered and commercialized in countries without large centralized waste treatment facilities, more specifically, biogas has become a common option for the on-site treatment of concentrated organic wastes such as animal manure, crop residues and sewage. Methane recovery is being employed at a variety of scales, from single farms to small communities. The methane, which is not "scrubbed" into it's constituent gases, is used as a heating fuel, as a mix with diesel fuel to power motors, for lighting and a variety of other appliance applications. methane appliances and light fixtures do differ slightly from propane and natural gas fixtures, but are commercially available.
We estimate that the NBSB will generate up to 116.8 tons per year, roughly 800 lb. per day of food waste from administrative, academic and dining sources. This amount of food waste would generate at least 650,00 cu. ft./year (1784/day) of methane,. The other byproduct of methane systems is a concentrated sludge which could be handled by secondary treatment such as land applications, irrigation and vermiculture.

We estimate that anaerobic digestion of 60,000 gpd (Sackett) at the NBSB could generate between 10,000 and 14,000 lb/year of methane, approximately 125,000 cu. ft./year or 343 cu. ft./day. This would only yield approximately 2127 total btu/d when combined with the food waste. This quantity would be sufficient to light all exterior paths and entrance with gas lights which are presently produced on the market in a modern efficient design.

The type, size and cost of a methane recovery system depends on the type and size of primary treatment. Most large anaerobic digestion systems will come with a methane recovery option. Other anaerobic systems, such as lagoons, would require a more extensive methane system.

FOOTPRINT

## 4) SUPER OXIDATION

SYSTEM DESCRIPTION

Super oxidation is the process of using solar radiation to disinfect wastewater by breaking apart organic compounds, thereby reducing their concentration to acceptable ranges. The process relies on solar or UV radiation and some type of semi-conductive molecule to trigger a chemical reaction, which in turn reacts with the organic compounds in the wastewater, ultimately converting everything to $CO_2$ and basic elements, which are not reactive to the environment. This system is most efficient when combined with a system that filters out larger particles in the wastewater, and a system that absorbs the carbon dioxide and mineral acids generated by the oxidation reaction. However, this system has also been shown to be a very effective way of mitigating contaminants (even herbicides and pesticides), which may seriously compromise other biological wastewater treatment systems.

The super oxidation process treats wastewater solutions up to several thousand parts per million of total organic carbon at a rate of 3 gal/min. It is not known to what degree that the 100% oxidized nutrient solids remaining in the system are readily available for biological assimilation for the purpose of the biological sequestering of carbon. Photocatalytic systems can be based on a variety of solar collector or UV radiator designs and hydroxly chemicals.

FOOTPRINT (PHYSICAL AND CHEMICAL)

The physical footprint necessary to treat a building with a peak of 1200 persons would make up approximately two containers 8 ft x 35 ft, assuming an 8 ft depth. No figures are available at this time for the quantity of CO2 generated in proportion to the liquid wastewater generated.

5) FOREST MANTLE SYSTEM

SYSTEM DESCRIPTION

Application of wastewater and sludge to vegetated lands such as field crops and forested lands is an old and evolving method of processing sewage wastes. Application in forested areas has been shown to increase the productivity of understory vegetation as well as stimulate increased tree growth. Wastewater may be applied to all ages and types of forests with sensitivity to the types and density of trees and understory and soil conditions (especially subsurface migration and permeability).

FOOTPRINT (PHYSICAL AND CHEMICAL)

Sludge or wastewater should be prefiltered to remove large bio-solid particles in order to prevent clogging of irrigation equipment and to facilitate rapid decomposition. A recent study showed an application rate of 850 gal/ac/day to an established oak forest increased tree diameter growth by 63%. Slightly more than 23 acres of forest would be required to process the *average* daily amount of NBSB wastewater. However, given a small existing forested area, this system can be effectively utilized in series with other wastewater systems. Further study is needed on soil and plant types in the forested area being considered.

## 6) WETLAND SYSTEMS

### SYSTEM DESCRIPTION

Wetlands and the microbial rock bed filter technique are one in the same system but are referred to under both names. The system is in essence is a bed within the ground composed of a certain size of stone that holds the root structure of plant species in it so that water flowing though is exposed to both the plant roots and the stone. The roots and stone act together to form a kind of armature onto which bacteria grows and feeds on the wastewater. The bacteria on the plant roots actually transform the nutrients into a form that is then useful for the plants to obtain food. The plants have another very important function in aerating the system. The plants can range from being flowers (canna lillies, calalillies, rainbow irises) to reed plants such as carrizo, phragmites, cattail, and bamboo). Two issues are important to understand. First, the plants need to be periodically cropped so the root density does not become so thick that water will not penetrate through (this issue is disputed by the Cornell team who have established a root only system with no gravel support). Second, if using decorative flowers, the cropping does not become a liability but an aesthetic advantage to the owners who must have cut flowers on tables throughout their buildings.

### FOOTPRINT (PHYSICAL AND CHEMICAL)

The physical footprint for the wetland system consists of a settling basin and wetland area. Both together are approximately 40- 50 square feet per person for gray and black water, thus requiring approximately 50,000 square feet, or about 1 acre, to accommodate the NBSB population. The greenhouse gas impact at this time is not known and will be reported at the January meeting.

7) WINDGROW

SYSTEM DESCRIPTION

A "windgrow" essentially describes an old system which originated at the end of last century in Paris, France in order for the population to treat the manure produced from its horse-based transport system and convert this into food for the population of the city. It is not a primary wastewater technique and requires the treated "bottom cake" from a primary system such as the lagoon, attached film bed, or photocatalytic systems to be utilized first. The system essentially uses conventional composting windgrows as raised planting beds for landscape plants or food crops. Windgrows are a method of composting material in a continuous pile that is periodically turned until complete composting aeration has occurred. Methods have been developed where an air pipe is placed down the middle of the pile with a reversing distribution fan at the end so that air can both be blown in to aerate the center of the pile or pulled through to aerate the outside of the pile. This method takes the place of the turning operation. In addition, windgrow composting is usually accomplished in a central location and then the finished product is transported for use elsewhere, necessitating energy expenditure in transport. By utilizing the compost in-situ to grow plants, energy transport costs are eliminated, thus the term "windgrow". Typically, windgrow compost is deficient in nitrogen (carbon to nitrogen ratio ideally occurs around 30 to 1). The use of septage (or "bottom cake" as produced in primary treatment systems) to increase the nitrogen content so that microorganisms can function is therefore a sensible marriage between the two systems. Similar methods of sewage processing based on windgrow composting have been established; see especially the Beltsville Aerated Rapid Composting (BARC) method.[1] Windgrow processing of wastewater in combination with some initial thickening of the wastewater by use of super oxidation or attached film bed techniques and careful selection of plants and wastewater application rate make this a feasible method of absorbing a significant amount of daily wastewater discharge. The amount of bulky materials such as landscaping debris or paper fiber available to mix with wastewater is an important factor in determining the footprint needed for the windgrow method.

FOOTPRINT (PHYSICAL AND CHEMICAL)

The physical footprint involves the placement of a 3-foot by 1-foot deep and 30 foot long bed every three weeks, producing in the order of 17 beds per year. It is important to realize that the growth of living matter in this type of system should occur promptly after the compost process is complete, so that $CO_2$ balancing can occur. It is also relevant to state

[1] The BARC method was developed by the United States Department of Agriculture and the National Park Service in the late 1970's.

that woody perennial plants as well as crops can better sequester carbon, therefore it is probably most sensible to only have some beds on exhibit at the immediate site and the bulk of bed activity in a designed component of the 100 acre park. This system would eventually be repeated on the same beds over a ten-year period so the footprint would actually be ten times the seventeen-bed area total for this system to operate. The chemical footprint of this system will be reported on at the January meeting.

## 8) VERMICULTURE

### SYSTEM DESCRIPTION

Vermiculture composting (or the use of certain varieties of earthworms) for the purpose of treating organic waste has been developed specifically to increase the quality of soil for land improvement beyond that of the composting techniques. The worms produce castings through their "grinding gizzard", a name given to the rapid fragmentation of organic that all earthworms possess. The castings are microbiologically active and make nutrients (nitrogen, phosphorus, potassium and calcium) more available to plants. The result is a high-grade horticultural plant growth media that is ten to twenty percent better than the best known medias on the market at a profit value of 50 cents per pound.

### FOOTPRINT (PHYSICAL AND CHEMICAL)

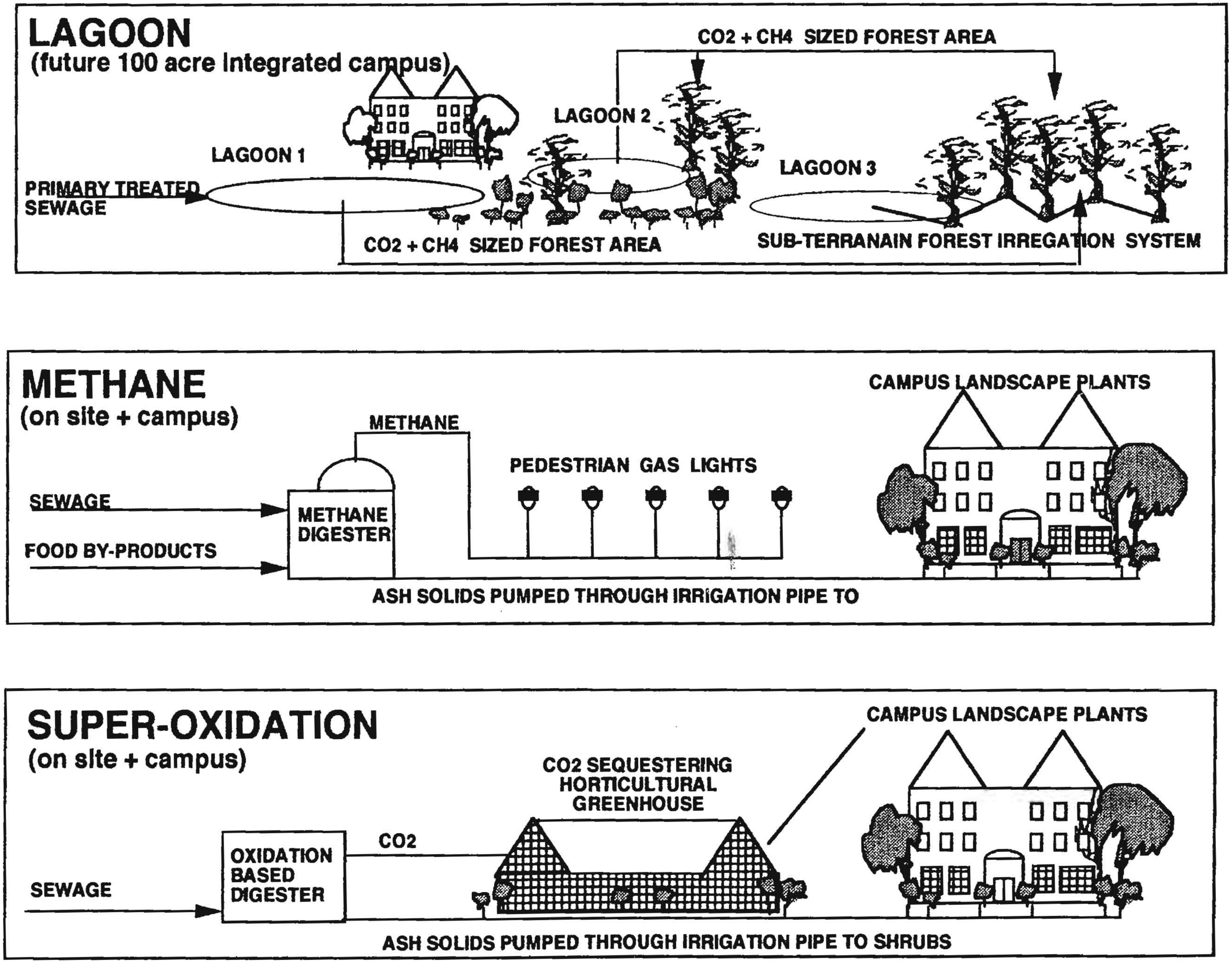
The physical footprint for the treatment of 1000 tons of organic material consists of a trough 128 feet long, 8 feet wide, and 6 feet high. The vermiculture compost area itself in addition to a pre-treatment area would be needed to *** and prepare the remaining liquids for use by further aerobic treatment before being applied to landscape plants. The area for pretreatment for this size bin is approximately 24 feet long by 16 feet wide by 4 feet high. Since the vermiculture system could treat both the solid organic and liquid waste for the building, the quality of material at this U.T. Houston facility would consist of 116.8 tons per year of organics from the restaurant, administrative and academic facilities. The solids portion of the liquid waste for these same facility areas is approximately 73 tons per year (at .5 lb. Liquid waste solid generated per person for 800 people) or a total of 116.8 + 73 = 189.8 tons per year for the facility. At approximately 1/5 the size of our 1000 ton per year system making a vermiculture area of approximately 26 feet long by 8 feet wide by 6 feet high, and a pretreatment area of 12 feet long by 8 feet wide by 4 feet high. Both these footprints can easily be placed on an urban site if treated material is removed.

## CONCLUSION

If each of the systems described were to be considered linked to each other various primary treatment options with various secondary treatment 16 variations are hypothetically possible. Some of these options are diagramed in the examples below. It is necessary to think of these in a life cycle balancing manner so that our stated objective of CO2 balancing occurs. Although all sizing numbers are not complete especially those that include the upstream emissions for manufacturing of components it appears that CO2 balancing is feasible. For example the estimate of 23 acres of forested land for the absorption of CO2 generated during usage can fit onto the secondary 100-acre site with space enough to spare to take care of upstream emissions. Similarly other scenarios seem to be feasible relative to spatial needs.

But there are questions that still need resolution. For example, are the materials left over from primary treatment available from a biological standpoint for the next stage of treatment or are they so inert resulting from excessive oxidation that they are worthless at the next stage. If connection between these elements cannot be made efficiently this issue violates our life cycle design principles that state that the continuation of flow integrity is necessary for continued resource balancing. The question of off-or on-site also remains an issue due to whether or not pumping or transport to the 100 acre site is feasible. Still another issue arises when we consider the total upstream CO2 burden of material manufacturing all the way through the life cycle system for water balance including the roof system, the cistern and other componentsthat make up the total water/wastewater life cycle.

Carbon dioxide and methane are two common by-products of almost every biological reaction involving decomposition, There is much work beginning to appear in the field and the actions being suggested by the Kyoto Accord related to land use planning and CO2 balance enables the this issue to be placed possibly in the forefront of our pedigogical campaign. in If this project is sincerely trying to develop a zero footprint or a chemically balanced footprint relative to greenhouse gases, it appears that this subsystem is a prime target.




| LIFE CYCLE BALANCING / WASTEWATER SYSTEM | FIGURE 1: OPTIONS 1-3 | NO SCALE CMPBS 1998 |
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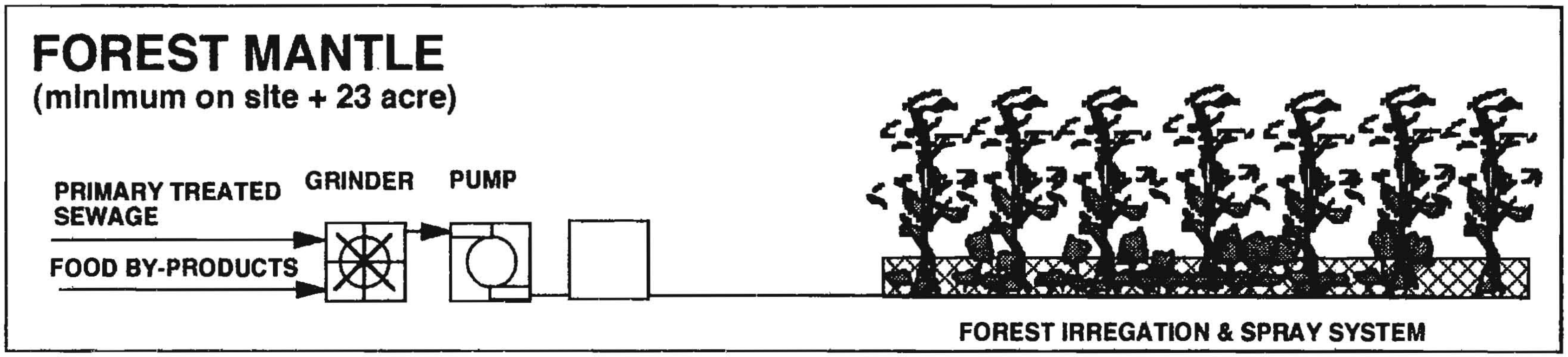


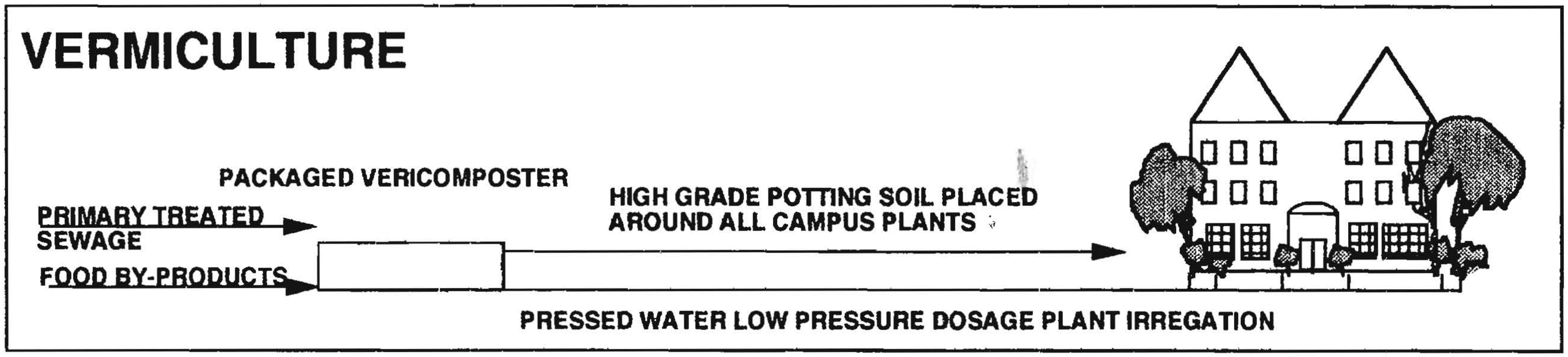


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| **LIFE CYCLE BALANCING / WASTEWATER SYSTEM** | **FIGURE 2:**<br>**OPTIONS 4-5** | NO SCALE<br>CMPBS 1998 |

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