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Technical Memorandum

Prepared for: Oberlin College

Project Title: Waste Heat Utilization Feasibility Study

Project No: 143518

Technical Memorandum

Subject: Heat Transmission and Waste Heat Utilization Alternatives

Date: December 14, 2012

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Abbreviations and Acronyms

EDI	Energy Developments, Inc
HEX	Heat Exchanger
HRU	Heat Recovery Unit
HWR	Heating Water Return
HWS	Heating Water Supply
MMBTU	Million British Thermal Units
MMBTU/hr	Million British Thermal Units per hour
psi	Pounds per square inch
WAS	Waste activated sludge
WEPF	Oberlin Water Environment Protection Facility

1. Executive Summary

This Technical Memorandum summarizes the findings of Phase 1 of the Waste Heat Utilization Feasibility Study. This study explores the viability of conveying waste heat from the Energy Developments, Inc. (EDI) landfill gas engine-generator complex to a nearby facility for utilization. The heat utilization facility alternatives considered include:

- Enhancements to the city's Wastewater Environment Protection Facility (WEPF) wastewater treatment or biosolids processing systems
- Composting
- Food production greenhouse

Heat can be conveyed using heat exchangers and above ground or underground hot water piping (Figure 1). The costs for aboveground and underground insulated systems are similar. Aboveground piping is less susceptible to corrosion, while underground heating system piping must be carefully designed and installed to prevent corrosion. Pipeline costs range from $170 per foot for very small 2-inch piping systems to $410 per foot for 6-inch piping to convey the full output of an EDI engine.

The EDI complex could supply heat, and possibly CO_2 to a greenhouse facility, similar to recent installations in California and Illinois. In addition, the following WEPF heat utilization alternatives appear to offer significant benefits, especially if the pipeline cost could be shared with another user such as a greenhouse.

- Batch biosolids pasteurization
- Heating biosolids drying beds
- Heating the nitrification tower

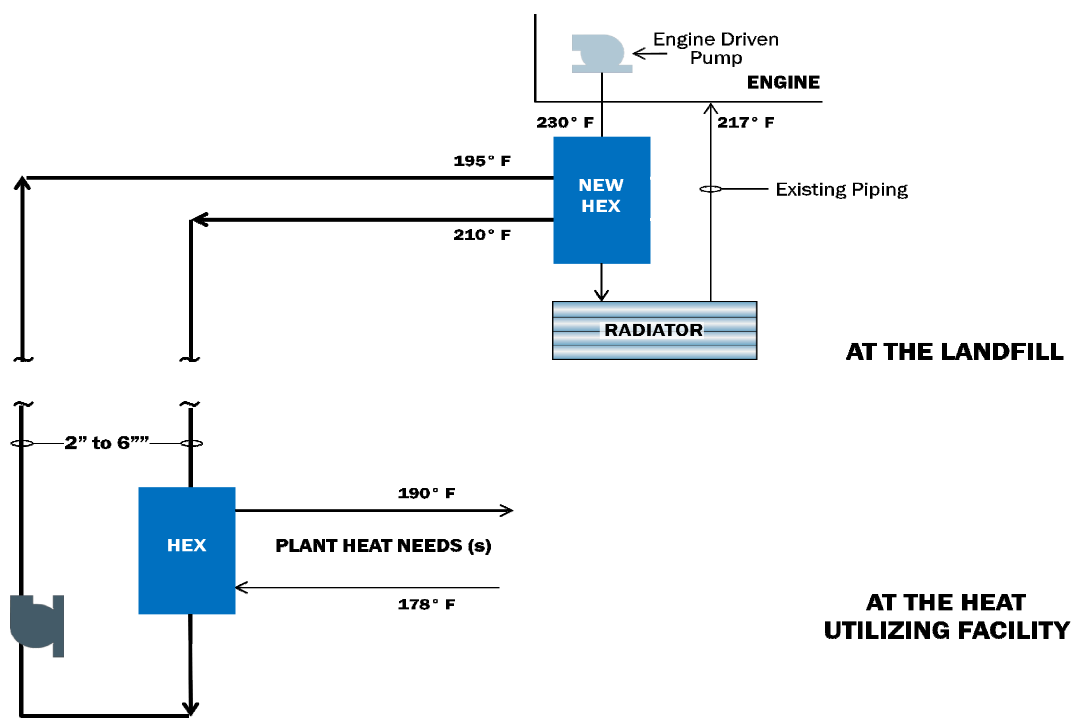

Figure 1.1. Overview of Heat Recovery System

2. EDI Interface

2.1 Existing Engine Cooling Equipment Description

The EDI energy recovery facility utilizes landfill gas to fuel ten new 1600 kW Caterpillar G3520C engine-generators, in addition to eight older units. Engine heat is rejected to two radiator-cooled loops, summarized in Table 2-1. The engines are fully loaded, so 3.0 MMBTU per hour of heat as nominally 200°F will be available for utilization. The engine jacket water loop is the largest and hottest heat source. The jacket water loop would be used for heat recovery because the higher temperature minimizes the transmission piping and downstream heating equipment size. The engine's exhaust heat is not captured.

The existing jacket water loop piping extends near grade level between the engines and radiators (Figure 2.1). A new plate and frame heat exchanger would be installed in this engine jacket water loop, as shown in Figure 1.1. The engine jacket water loop is served by an engine-driven pump that is part of the engine assembly. The plate and frame heat exchanger will increase the head conditions of this pump. Caterpillar has indicated that the pump can tolerate an extra 5 psi in head loss through a new heat exchanger (Attachment A, Jacket Water Pump Curves).

Table 2-1. Engine Heat Recovery Loop Operating Conditions

	Heat Rejection (100% Load, MMBtu/hr)	Flow (lb/hr)	Fluid Temperature (Radiator in/out, °F)	Fluid
Auxiliary Loop (Intercooler)	1.3	62,460	155/130	50% Ethylene Glycol
Engine Jacket Water, Oil Cooler, and AC	3.0	261,600	230/217	50% Ethylene Glycol

Source: Air Cooled Exchanger Specification Sheet, Smithco Engineering

Figure 2.1. Engine-Radiator Piping System at EDI

2.2 Heat Availability and Purchase

2.2.1 Heat Source Redundancy

One engine will provide sufficient heat for the alternatives considered later in this report, with the possible exception of a sizeable greenhouse. Therefore, the heating system could be connected to just one engine's cooling loop, if a redundant heating source (e.g. the WEPF hot water boilers) is available. According to EDI, their engines have a historic average availability of 90%. Most of the outages are planned maintenance activities conducted over the third shift, so the heat utilization facilities would usually have advanced notice of a heat interruption. Alternatively, the capital cost for installing a heat exchanger on a second engine would not be great.

2.2.2 Potential Purchase Terms

Unlike other utility transactions such as sale of electricity or natural gas, there are no state or federal regulations governing the sales of thermal energy. Heat is generally sold by the BTU, based on a metering system that measures flow and supply/return temperatures (Figure 2.1). The metering system could be located either at EDI or at the purchaser's facility.

EDI has informally indicated that they would supply waste heat from two engines at a selling price of about 50% of the price of natural gas. EDI would not participate in any capital expenditures for equipment needed for the project. O&M costs for the equipment would also be the purchaser's responsibility (Ted Dunchak email, 12/6/12).

It should be noted that the heat consumer would be justified in negotiating a discount on the heat sale under the interruptible conditions associated with heat from one engine.

Key aspects of the heat sale contract terms would include:

- Specified minimum hot water flow and supply temperature
- Maximum water pressure
- Hot water/fluid composition
- BTU metering protocols
- Permitted emergency interruptions
- Unscheduled interruptions in delivery of hot water
- Pipeline ownership boundaries ("Delivery Points")
- Default terms – EDI or buyer

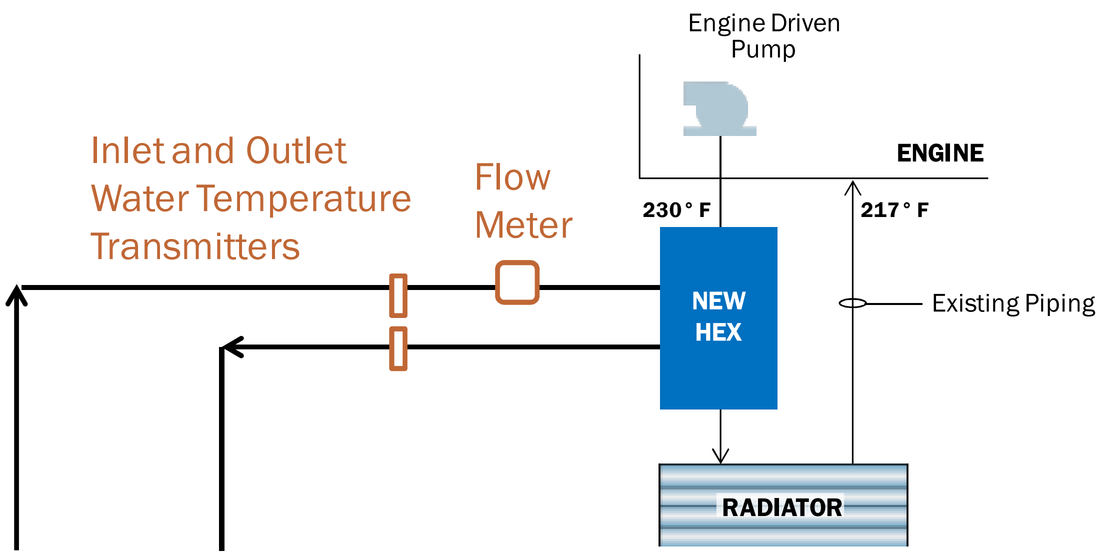

Figure 2.2. BTU Metering Arrangement

3. Heat Transmission

In order for the head generated by the engines to be utilized at the WEPF, compost site, or future green-house, it must first be transferred from the engine location to the point of use. The cooled transfer media is then returned to the engines and passes again through the heat exchanger, completing the pumping loop.

Items requiring careful consideration include:

- Pipeline routing
- Fluid composition
- Pipeline installation (buried or above grade)
- Pipeline materials of construction

3.1 Pipeline Routing

The landfill engines and WEPF are on adjacent parcels and separated by only about 1800 feet if directly connected. However, a direct route between engines and the plant would require construction through a heavily wooded area, and may require a stream or wetland crossing.

A less direct route, but with simpler, less environmentally intrusive construction, involves following an existing right-of-way along the northern and western edge of the city's property (3500 linear feet) as shown in Figure 3.1. The pipeline could probably be routed on the west side of the road to avoid obstructing access to the existing shooting range and animal shelter. The proposed route would generally follow the same path as existing overhead electrical wires.

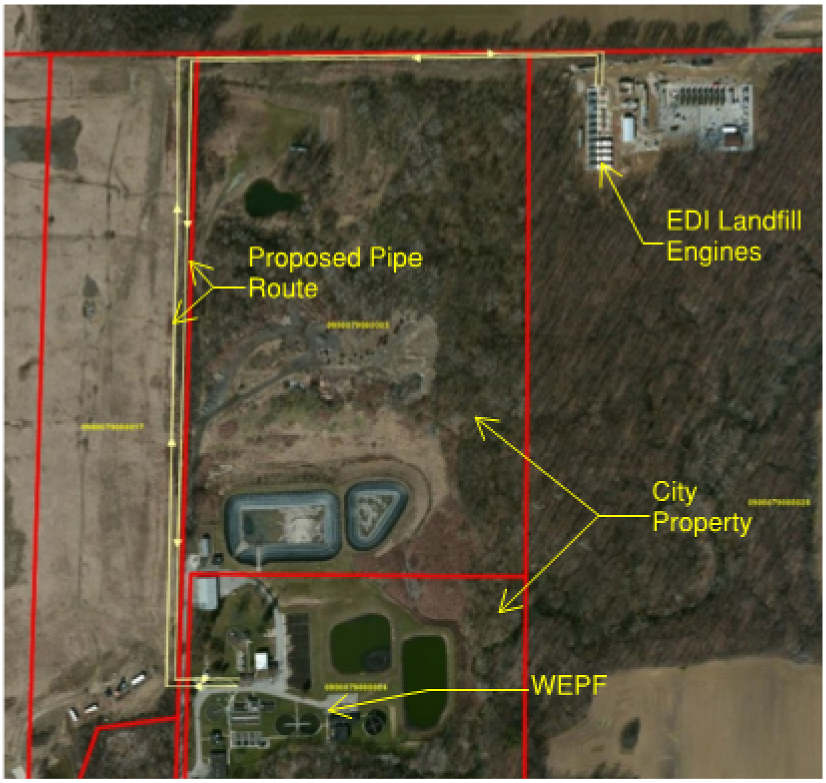

Figure 3.1. Proposed hot water pipe route along access road and existing right-of-way

3.2 Heat Transfer Medium

Hot water is the most common and simplest medium for transferring the 210°F engine heat. Virtually all of the heat utilization alternatives presented in this report can utilize heat in the form of 210°F pressurized hot water, although the biosolids dryer and effluent disinfection alternatives would benefit from a higher temperature heat source. Hot water is the safest option due to the lower operating pressures, and no special environmental precautions are required in case of leaks.

If a future heat transfer alternative requires a warmer temperature heat source, EDI would need to add exhaust heat recovery to an engine, and the heat transfer medium would need to be reconsidered. Table 3-1 shows a comparison of available heat transfer fluids, along with typical uses and limitations.

The recommended fluid is pressurized hot water with a very small amount of biodegradable non-hazardous water treatment chemicals to scavenge out the dissolved oxygen and to minimize pipe corrosion.

Table 3-1. Heat Transfer Media Options

Heat Transfer Media	Heat Source at the Engines	Temperature range, approx, °F	Approx operating pressure, psig)	Issues or Special Concerns
Medium temperature hot water	Engine jacket water, Engine exhaust gases	180 to 240	5 to 15	not hot enough, thus not applicable to all types of sludge dryers
High temperature hot water	Engine exhaust gases	300 to 400	60 to 250	high fluid pressure, significant thermal expansion,all leaks will flash to steam
Hot thermal oil	Engine exhaust gases	350 to 450	5 to 25	expensive special fluids, significant thermal expansion, possible fire concerns
Low pressure steam	Engine exhaust gases	224 to 248	5 to 14	condensate return and steam hammer concerns
Process steam	Engine exhaust gases	250 to 380	50 to 200	needs continuous staffing at steam production site
Hot engine exhaust gases	Engine exhaust gases	750 to 1000	0.8	very large diameter stainless steel pipe, extreme thermal expansion

3.3 Pipeline Installation Alternatives

3.3.1 Above Ground Piping Installation

The conceptual design for an above ground piping system at elevated temperatures includes Schedule 40 carbon steel piping with welded joints and fiberglass insulation with continuous aluminum jacketing. Steel pipes that are 3- to 6-inch diameter would need to be supported approximately every 10 feet, with somewhat greater spacing possible for larger diameter piping. Supports could be accomplished by a concrete pillar drilled to below frost depth with a small galvanized steel frame to which the pipes can be attached. The steel pipes will expand over 1-inch per 100 feet as they become heated, so care must be taken to design an expansion control and support system which accommodates that movement. Figure 3.2 shows an above ground installation of insulated pipe.

The main advantages of the above ground installation are that the pipe is accessible for inspection and maintenance when required and the pipe is less susceptible to corrosion when compared to buried installa-tions. The main disadvantage is that above ground piping is more vulnerable to damage either by accident or vandalism, although city staff feels that the minimal amount of traffic near the pipeline would limit this risk.

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Figure 3.2: Typical above ground insulated pipe installation

3.3.2 Buried Piping Installation

The conceptual design for a buried installation includes pre-insulated piping which can be directly buried in a typical pipe trench. Pre-insulated piping is a factory-built piping system which includes Schedule 40 steel pipe, polyurethane foam insulation and a PVC or FRP jacket. Insulated pipe segments are delivered to the job site as a unit with the insulation held back from the end of the carrier pipe to allow the joints to be assembled. Joints are then insulated in the field with an insulation kit purchased from the pre-insulated pipe manufacturer. Fittings (elbows, tees, etc.) are standard products purchased by the installing contractor and insulated in the field with a fitting insulation kit provided by the pre-insulated pipe manufacturer. There are multiple manufacturers of pre-insulated piping systems, including Perma-Pipe and Thermal Pipe Systems. Figure 3.3 shows a typical pre-insulated pipe section.

The main advantage of the buried installation is that the pipe is below grade protected from vandalism and accidental damage and is un-obtrusive. The pipe route is less critical because the buried pipe will not obstruct access to any drives. The disadvantage of the buried installation is that the pipe is more difficult to inspect and maintain. Underground piping also has a higher potential for corrosion due to below ground moisture, so jacket integrity is critical to preventing water from contacting the piping.

Figure 3.3: Pre-insulated pipe section

3.4 Pipeline Project Costs

A budgetary estimate was developed in order to make an economic comparison of the pipe installation alternatives, including above ground insulated piping, the buried pre-insulated piping, and the buried bare piping as described above. Project costs were itemized for a 4-inch diameter pipe and a 3500 linear foot pipe route from the EDI engines to the WEPF boiler room. The above ground and below grade insulated piping cost estimates are essentially equal, with a possible slight cost advantage for the below-grade piping.

Table 3-2. Cost Comparison for 4" Piping[2]

Item	Installed Cost - Above Grade[1]	Installed Cost - Below Grade Insulated[1]
Cleaning and Grubbing	$3,374	$3,374
Concrete piers, pipe support framing, etc.	$90,447	
Excavation and Backfill		$111,612
Pipe and Insulation	$520,075	$434,815
Contractor General Conditions[4]	$130,710	$114,372
EOPCC Contingency (25%)[3,4]	$180,672	$157,627
Escalation to Midpoint of Construction[4]	$25,173	$22,026
Engineering (20%)[4]	$196,000	$169,000
TOTAL	**$1,176,500**	**$1,012,800**

1. Cost based on 4" supply and return pipe - 3500 linear feet each.

2. Class 4 estimates according to the Association for the Advancement of Cost Engineering.

3. Engineers Opinion of Probable Construction Cost

4. Item costs based on varying percentages of estimated construction cost.

The 4-inch pipe considered in Table 3-2 would be large enough for most of the heat utilization alternatives, but more expensive 6-inch piping would be required for alternatives that used all of the engine's heat (refer to Figure 4.1). Smaller thermal loads could be served by 2-inch or 3-inch piping, but the reduced piping cost may not be worth the penalty of reducing the hot water pipeline system's capacity to serve future increases in heat utilization.

A range of costs for all pipe sizes are presented in Figure 3.4 in terms of unit costs (dollars per linear foot of supply/return route, installed) for use in estimating pipeline costs for various heat utilization alternative locations, such as the compost or potential greenhouse sites. The high end of the cost range is for insulated piping systems, and the low end of the range is for bare below grade piping. Figure 3-4 also shows the relationship between the conveyed heat load, corresponding hot water flow rate and the necessary pipe size.

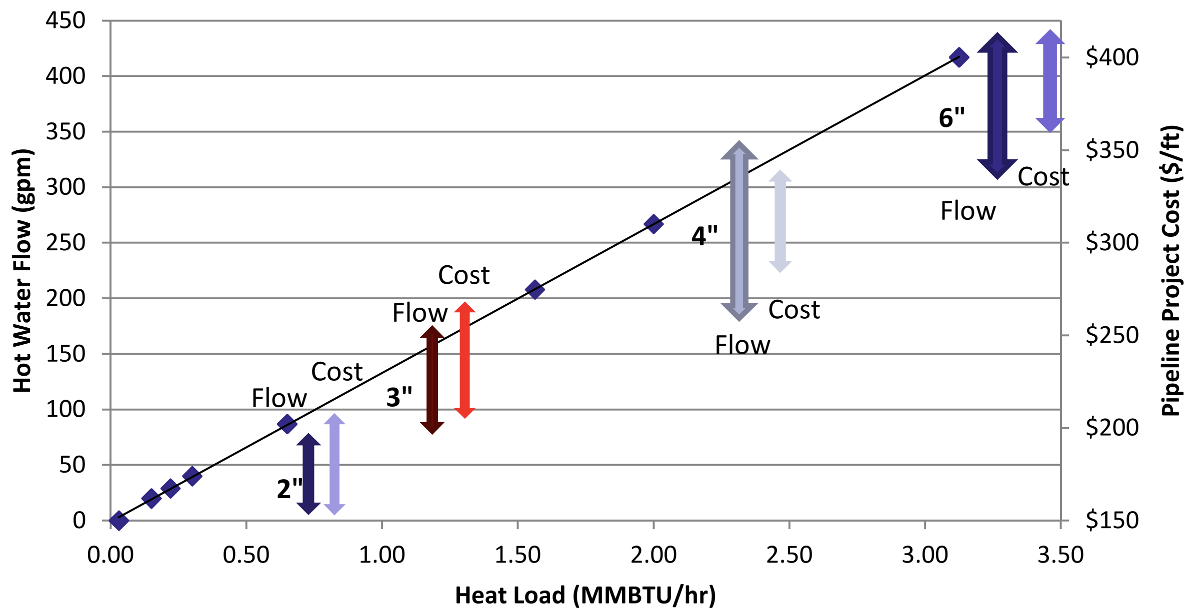


Figure 3.4: Ranges of Project Cost per BTU

3.5 Pipelines Conclusions

The estimated cost for the insulated pipeline alternatives (insulated steel pipe on above ground supports or buried pre-insulated steel pipe) are close enough to each other that a few design choices could change a recommendation based solely on cost. As an example, the cost presented above for the 4” pipe includes galvanized steel frames on concrete supports to hold the insulated pipe. If the design could accommodate installing the pipe directly on the concrete pillars instead (with periodic anchors and guides as needed for expansion), that change alone would be enough to drop the above ground cost estimate below the buried estimate. Since both estimates include large contingencies, the price difference alone is not sufficient to favor either the above ground or buried pre-insulated pipe.

Alternative underground piping and insulation systems were considered as a means to reduce the pipeline cost, but the pre-insulated system used for the conceptual estimate is the only design that has a positive track record in resisting corrosion.

4. Heat Utilization for Wastewater Treatment

4.1 Heat Utilization Alternative Summary

In general terms, heat is useful in wastewater processes for:

- Evaporating water
- Killing pathogens
- Promoting the growth of a temperature-sensitive bacterial community

The heat utilization alternatives in Table 4-1 each utilize one of these mechanisms, either to improve biosolids handling or liquid stream processes. The amount of heat required for each of these alternatives varies widely, as noted in Figure 4.1. The feasibility and benefits of each of these alternatives are evaluated in the following sections, with the highlighted alternatives identified as being the most promising heat utilization alternatives at the WEPF.

Table 4-1. WEPF Heat Utilization Alternatives

Biosolids Handling	Liquid Stream
Utilize EDI heat in lieu of biogas	Nitrification tower (Winter/Spring)
Thermophilic digestion	Effluent pasteurization in lieu of UV (May-Oct)
Batch pasteurizer for Class A	
Food waste digestion	
Heat sludge drying sand beds	
Low temperature belt dryer	
Solar sludge dryer	

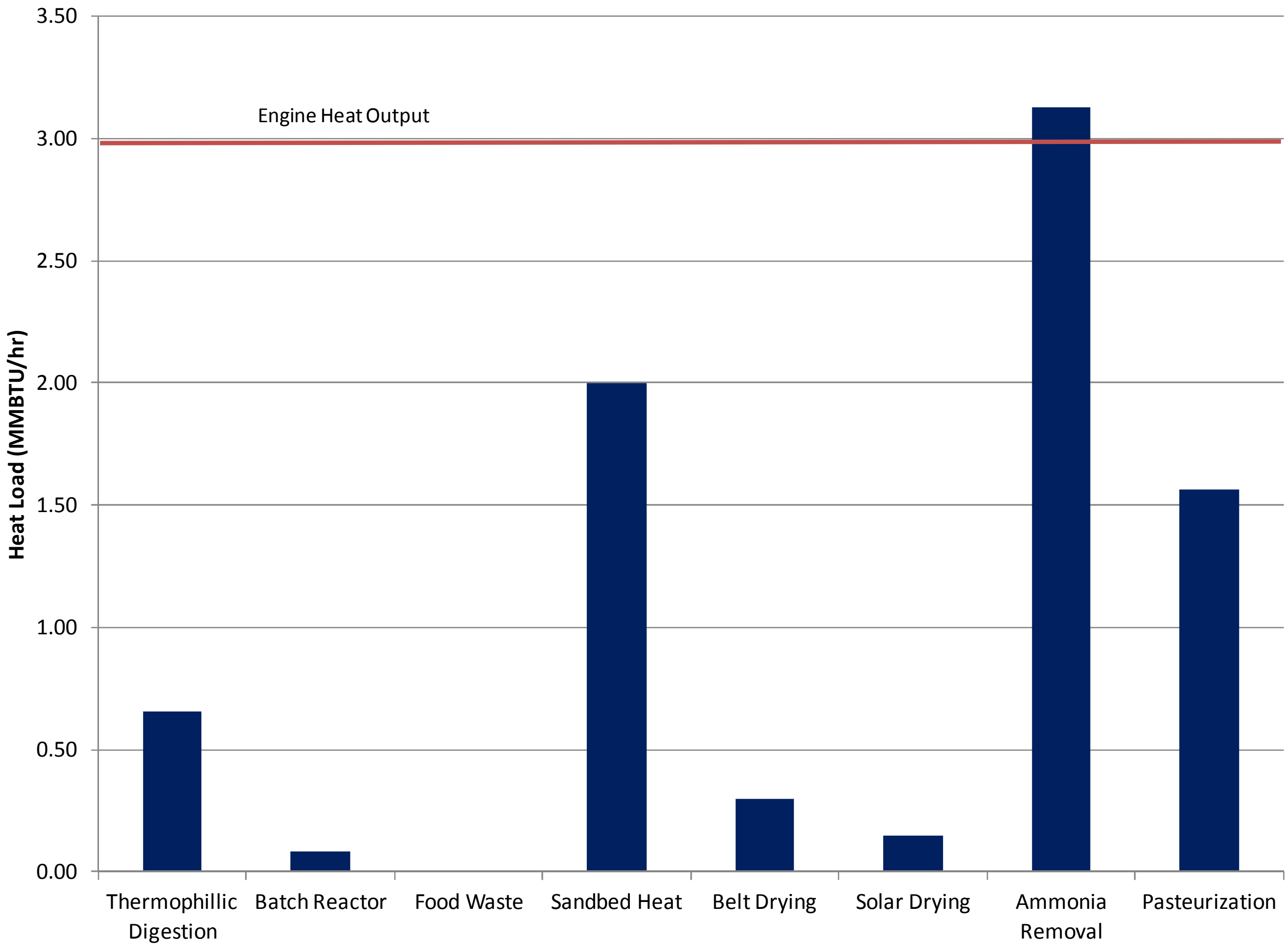


Figure 4.1. Comparison of Heat Demands (MMBTU/hr)

4.2 Solids Handling

4.2.1 Existing System Background

The WEPF generates an average of one ton per day of raw sludge. Although the WEPF has both aerobic and anaerobic digestion facilities, the plant has recently been routing both the primary sludge and WAS to the anaerobic digester to reduce blower energy consumption. Approximately 8,000 gallons of sludge per day is sent to digestion, with an average solids concentration of 3%.

Digested solids are batched out to lagoon or sand drying beds. Lagooned solids are dewatered on a belt filter press prior to land application.

The current WEPF solids handling system has several unique features to be considered:

- Biogas from the anaerobic digester is currently utilized for digester and building heat.
- Future power generation from surplus biogas is being implemented by plant staff.
- Sludge drying beds are used in the summer and produce a very dry product.

- Lagoon solids storage is used in the winter. Long lagoon detention times promote further solids destruction.
- The solids are beneficially reused as a soil amendment via land application on local agricultural fields.
- The land application program costs are comparatively reasonable, $18,000 per year

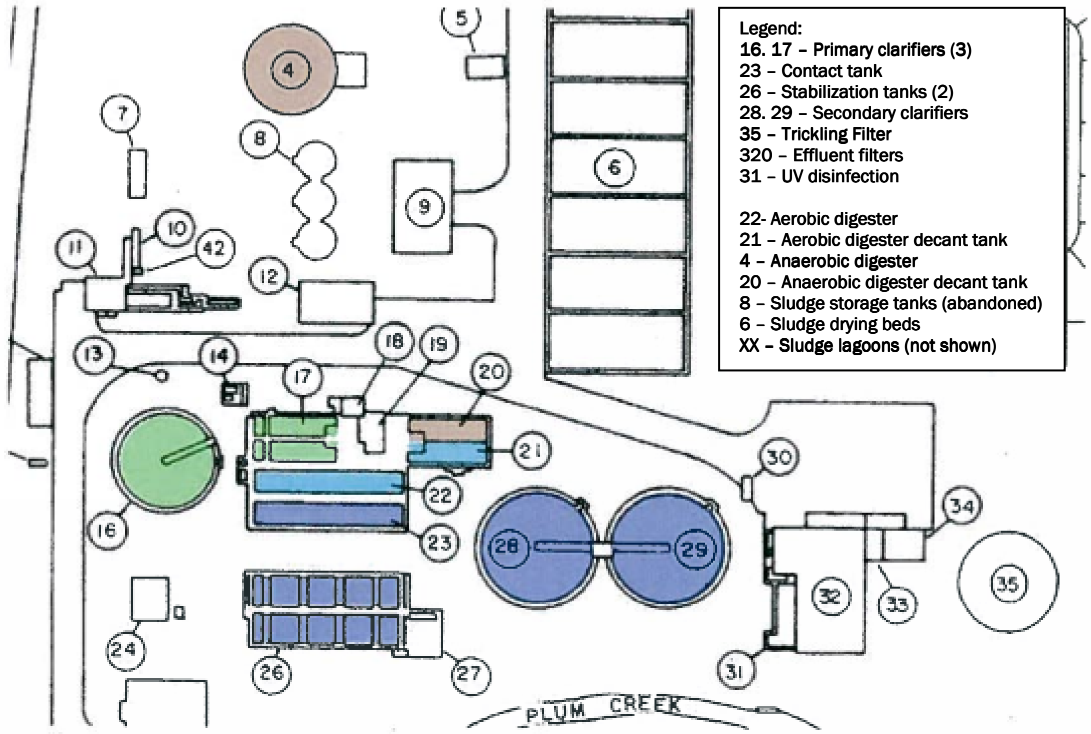


Figure 6. Oberlin WWTP layout.

Figure 4.2. Oberlin WEPF Facilities

4.2.2 Utilize EDI Heat in Lieu of Biogas Heat

Alternative Summary: EDI heat could be used in lieu of the WEPF hot water boilers.

Background: The WEPF operates hot water boilers that burn digester gas for digester heating and building heat. If insufficient biogas is available, natural gas is used to supplement the boiler fuel, at a cost of $5,000/year. In warmer weather surplus biogas is flared. A 30 kW engine generator has been purchased for use in utilizing surplus biogas.

Heating Benefits:

- Eliminates WEPF boiler maintenance and natural gas use
- Allows biogas engine to operate continuously, even in cold weather
- Allows 100% of biogas to produce power, maximizing the engine's power production

4.2.3 Thermophilic Digestion

Alternative Description: EDI heat could be used to supply the additional heat required for thermophilic digestion.

Background: A thermophilic digestion process raises the digestion temperature from 98°F to 128°F. Thermophilic digestion has been used by several wastewater facilities because 30% additional solids can be processed within the available tankage. In other words, the required digester hydraulic residence time is less for thermophilic systems.

Although the thermophilic process is considered an effective means of killing pathogens, the process will not produce Class A biosolids without batch tanks because pathogens from the raw sludge feed can short-circuit to the digester outlet.

Heating Benefits:

- Thermophilic digestion provides minimal benefit since the WEPF does not require additional digestion capacity

4.2.4 Batch Biosolids Heat Treatment

Alternative Description: EDI heat could be used to supply the additional heat required for post-digestion batch treatment at high temperature.

Background: Pathogen reduction alternative P-8 of the Ohio biosolids regulations outlines the time and temperature requirements to achieve Class A pathogen reduction in a batch process (Table 4-2). There are three existing, unused sludge storage tanks, each able to store sludge for 3-5 days at current sludge generation rates. The three tanks could be staged so that one would be filling, one holding at elevated temperature, and one emptying. According to plant staff, the tank concrete is in good condition, but the covers would need to be evaluated. In addition, new pumping and heating equipment would be required.

Table 4-2 Time and Temperature Requirements

Temperature (°C)	Temperature (°F)	Duration (days)	Duration (hours)	Duration (minutes)
50	122	5	-	-
54	129	2	-	-
58	136	-	10	-
62	144	-	3	
66	151			42

Ohio Biosolids Rules, 3723-40-04, paragraph (B)(8)(a)(iv) for sewage sludge less than 7% TS and batch time greater than 30 minutes

Heating Benefits

- Class A (Exceptional Quality) biosolids
  - Potential public distribution
  - Less biosolids regulation
  - Improved quality for agricultural use

Risks:

- Ammonia odors from heated biosolids may require odor control

4.2.5 Codigestion of Food Waste: Stevenson Hall

Alternative Description: A small amount of EDI heat could be used to heat pulped food waste fed to the WEPF anaerobic digester.

Background: Oberlin College currently hauls food waste to the Cleveland area for composting. Stevenson Hall at Oberlin College has a pulping system to homogenize the food waste and remove non-degradable items. This processed waste is likely to be suitable for addition to an anaerobic digester system. Based on our preliminary analysis summarized in Table 4-3 below, the WEPF anaerobic digester has sufficient hydraulic and organic loading capacity to accept this waste.

Ideally, this food waste would produce biogas that could be beneficially used to produce electricity. It must be noted that achieving this aim requires installation of the engine. In addition, the 30 kW engine appears to be somewhat well matched to the existing biogas production. If the engine ends up being fully loaded with the existing biogas stream, the food waste biogas would not provide additional electrical production unless additional engine generator capacity is installed.

Table 4-3. Oberlin College Food Waste Digestion – Pulped Waste from Stevenson Hall

Parameter	Value
Wet weight from college	400 lb/day[1]
Percent of total college food waste	25-30%
Dry solids content	23%
Solids content for digestion	8%
Volume to digestion	138 gal/day
Digestion organic load increase	24%
Power output	2.1 kW or $1000/yr

[1]*During school year*

Heating Benefits

- The heating requirement for this food waste is very small, but food heating could be an ancillary benefit if EDI heat is conveyed to the WEPF for another use.

4.2.6 Heat Biosolids Drying Sand Beds

Alternative Description: EDI heat could be used to heat the biosolids sand beds.

Background: During summer months, solids are spread in a thin (5-7-inch) layer on the sand beds. The WEPF has optimized their use of the sand drying beds, achieving very dry cake product (40-50% TS) without polymer addition or mechanical dewatering. However, the sand beds can only be used from April to September due to freezing conditions.

Heat could be supplied to the sand beds with an imbedded sand heating coil system similar to the one shown in Figure 4.3.

Heating Benefits

- Extend drying sandbed season, reducing belt filter dewatering expenses (polymer, power, labor)
- Reduce drying time, increasing sandbed capacity
- Pathogen reduction

Figure 4.3. In-bed Heating – PEX Tubing

4.2.7 Low Temperature Biosolids Dryer

Alternative Description: EDI heat could be used in a mechanical dryer to make a granular biosolids product.

Background: Mechanical sludge dryers are used to create a dry biosolids pellet for use as either fertilizer or fuel. Conventional dryers use high intensity heat sources such as biogas, natural gas, or high pressure steam. Recently, belt dryer systems have been developed to use lower temperature heat, similar to the EDI heat source. These dryers consist of an enclosed belt and a heated air circulation system (Figure 4.5). The biosolids are extruded onto the belt to maximize their surface area (Figure 4.6).

Heating Benefits

- Class A biosolids
- Minimal land application costs

Risks

- Significant electrical energy use for heated air circulation
- System complexity
- High project costs

Figure 4.5. Belt enclosure with heated air circulation

Figure 4.6. Sludge extrusion onto belt

4.2.8 Solar Greenhouse Biosolids Dryer

Alternative Description: EDI heat could be used to heat a biosolids-drying greenhouse.

Background: The biosolids sand beds are not covered, so precipitation can disrupt the drying process. The process could be enhanced, either by adding an open-sided roof or a closed, heated greenhouse. The open-sided structure could utilize the sand-heating concept introduced in Section 4.2.6.

Enclosed greenhouse ("solar") dryers are a recent technology. Solar radiation is used to evaporate the water in the biosolids. Supplemental heat can speed drying and reduce the greenhouse size. Automated agitation devices, such as the one shown in Figure 4.7 are used to break up crusts and expose wet surfaces.

Heating Benefits

- Class A biosolids at 90% TS
- Heat minimizes enclosed greenhouse size

Risks

- Agitation equipment access
- Product not pelletized, could be dusty
- High project cost

Figure 4.7. Solar biosolids drying greenhouse with agitation unit

4.3 Liquid Stream Heat Utilization Alternatives

4.3.1 Heat to Improve Wastewater Ammonia Removal

Alternative Description: EDI heat could be used to heat the wastewater entering the nitrification tower.

Background: Wastewater temperatures dip during cold weather, and especially during the spring thaw (Figure 4.8). The flow of cold air through the tower also has a cooling effect. Nitrification is inhibited by low water temperatures, so ammonia removal in the nitrification tower is less effective. Improved performance may be possible via controlled airflow and adding heat to the nitrification tower wet well to raise the temperature from approximately 50°F to 56°F.

Heating Benefits

- NPDES Permit compliance
- Effluent quality
- Possible capacity to accept more leachate

Risks

- Heater fouling from debris, scale, or biological material

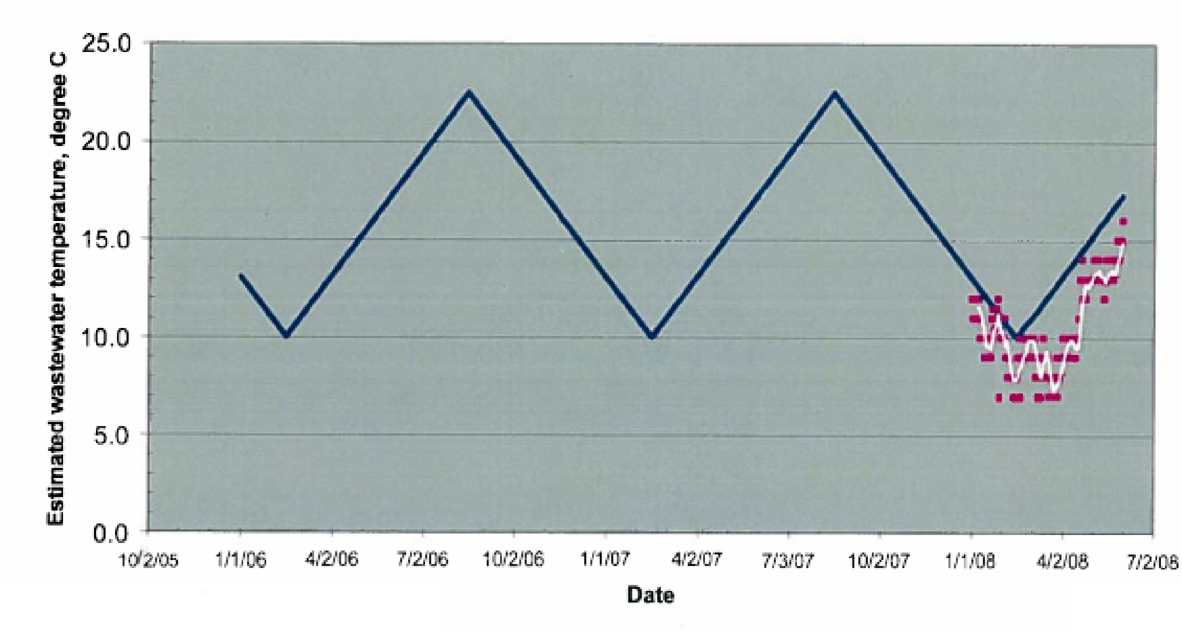


Figure 4.8. Late winter effluent wastewater temperature dips to 10°C

4.3.2 Wastewater Pasteurization

Alternative Description: EDI heat could be considered to pasteurize the effluent using emerging thermal disinfection technology.

Background: The WEPF currently uses UV disinfection to disinfect their effluent. This system works well, but consumes electricity.

A new thermal disinfection technology has been successfully pilot-tested (www.pastechgroup.com). This technology uses high temperature exhaust heat to raise the effluent temperature to 180°F for 8 seconds. A second heat exchanger recovers this heat to preheat the flow, and limits the overall effluent temperature increase to around 3°F. Adapting this system for use with hot water instead of engine exhaust could be a significant challenge to utilizing this technology at the WEPF.

Heating Benefits

- Reduce power use for UV
- No UV bulb maintenance

Risks

- Emerging technology
- Thermal effluent quality limits
- Adaptation for hot water instead of exhaust
- Not currently accepted by OEPA

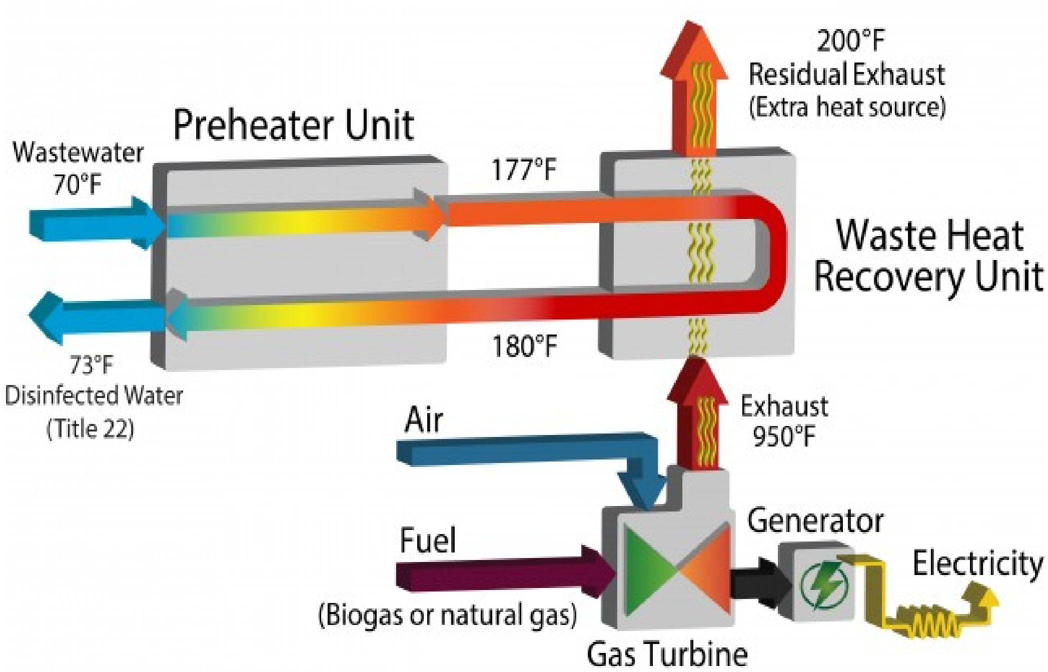


Figure 4.9. Thermal disinfection schematic

4.4 WEPF Heat Utilization – Strongest Alternatives

The following WEPF alternatives provide the most significant benefits and lowest expected capital costs.

SOLIDS TREATMENT

- Utilize EDI heat in lieu of biogas heat
- Batch pasteurizer
- Heat sludge drying sandbeds

Liquid Stream

- Nitrification tower heating (Winter/Spring)

A heat pipeline to the WEPF could serve one or more of these alternatives. While none of the alternatives initially appear to be justified on cost savings grounds, they all support the city's sustainability and environmental stewardship goals.

5. Heat Recovery Greenhouse

5.1 Engine/Greenhouse Synergies

The Oberlin Project has made preliminary investigations of using EDI heat for a local food production greenhouse. Greenhouses that are coupled with engine-generator facilities can take advantage of the following engine outputs, which would otherwise be wasted.

5.1.1 Heat Recovery

Heat recovery is the most common approach to coupling engines and generators. The hot water system presented in Sections 2 and 3 of this report is suitable for use with most conventional greenhouse heating systems. The cost for conveying this heat will depend on the greenhouse size and resulting heat loads. The cost data in Figure 4.4 can be used to estimate the pipeline cost once the BTU requirement and pipeline length are known.

5.1.2 CO_2 Recovery

CO_2 recovery allows the greenhouse to take advantage of the fertilization effect of elevated CO_2 in the growing area. For example, the exhaust from a 1.6 MW engine (similar to the EDI engines) would fertilize approximately 3-4 acres of tomatoes[1]. In order to introduce the CO_2 into the greenhouse, the exhaust gas must be scrubbed to remove nitrogen oxides (NO_x), carbon monoxide (CO), and unburned hydrocarbons. The practical limitation on transferring CO_2 from engines to a greenhouse is the size and expense of the conveyance duct for the hot exhaust. Exhaust duct runs greater than a few hundred feet are probably not practical.

5.1.3 Water Recovery

Systems that practice CO_2 recovery can also utilize the condensed moisture in the exhaust gases for irrigation.

5.2 Example CHP/Greenhouse Facilities

The following greenhouse facilities are examples of the type of CHP/greenhouse synergies described above. Many European facilities have also adopted this approach.

Five Oaks Landfill/Rock Solid Produce

- 2008
- Landfill gas
- Waste Management
- Taylorville, IL
- 3.2 MW engine complex, $5 million
- 4 acre greenhouse, $5 million
- Heat only

Houwelings Tomatoes

- 2012
- Natural gas

- Camarillo, CA
- 8.7 MW engine complex
- 125-acre greenhouse
- Heat, CO2 and water recovery

California State University - Northridge

- 1 MW Fuel cell complex
- Natural gas
- Heat utilized for buildings, domestic hot water, and pool
- Engine exhaust scrubbed for greenhouse CO_2 enrichment
- $5 million, fuel cells only

Figure 14. Five Oaks

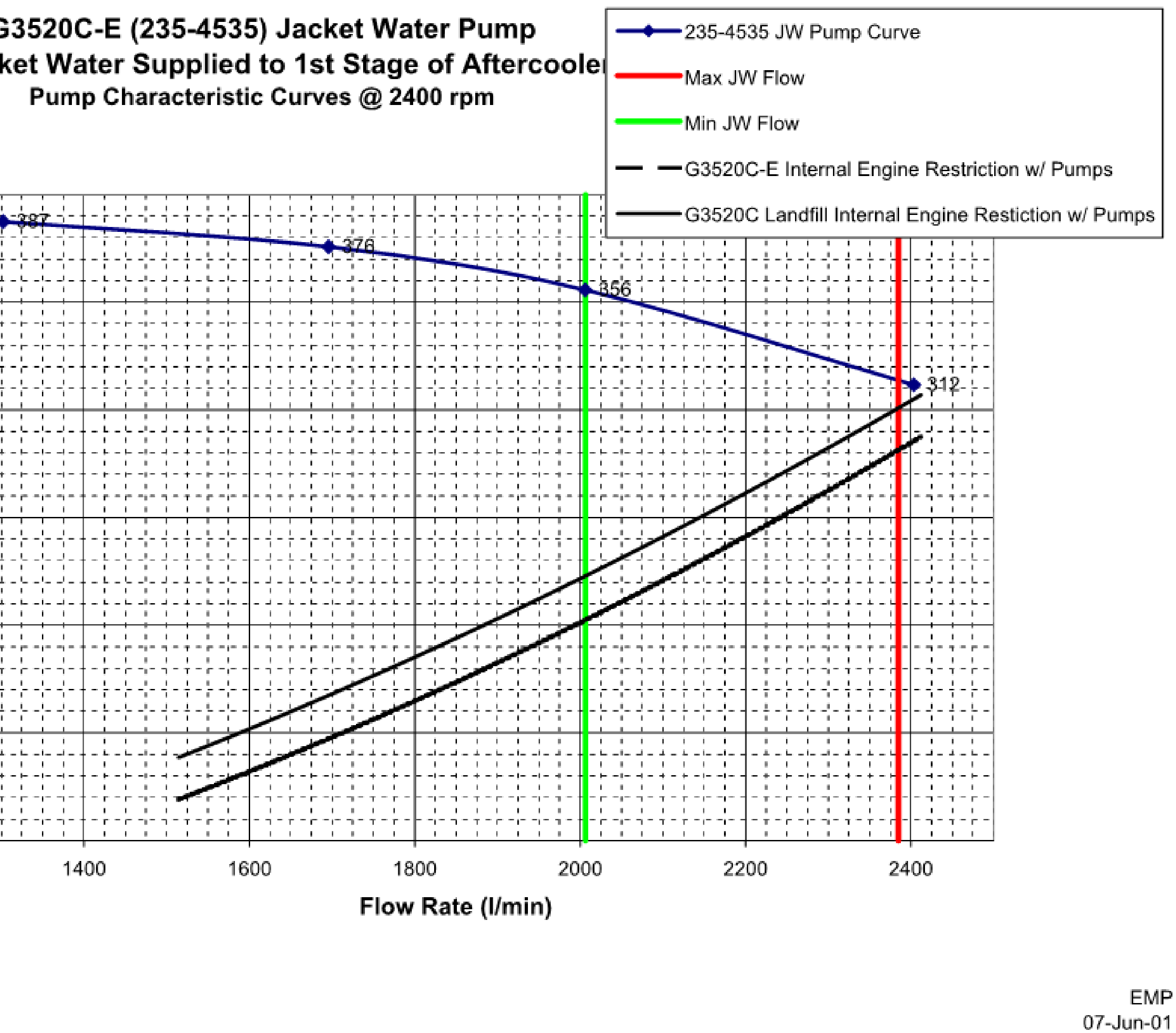
Figure 15. Houwelings Tomatoes

References

[1]Caterpillar, *Cogeneration in Greenhouses, Electric Power & Cogeneration Application Sheet,* 2009

Attachment A: Engine Cooling Water Pump Curves

Source: Kevin Abke, Ohio CAT


G3520C-E (235-4535) Jacket Water Pump
ket Water Supplied to 1st Stage of Aftercooler
Pump Characteristic Curves @ 2400 rpm
235-4535 JW Pump Curve
Max JW Flow
Min JW Flow
G3520C-E Internal Engine Restriction w/ Pumps
G3520C Landfill Internal Engine Restiction w/ Pumps
387
376
356
312
1400
1600
1800
2000
2200
2400
Flow Rate (l/min)
EMP
07-Jun-01

Attachment B: Composting Feasibility

Source: Joel Alpert, PhD

Introduction

Composting is the controlled biological decomposition of organic matter under aerobic conditions. There are numerous composting methodologies, but there are several key parameters that all methods must control: feedstock characteristics, moisture content, oxygen supply and temperature. In addition, many composting facilities also include pre- and post-processing to improve operations and quality of finished compost. Composting methods can be generally classified as windrow facilities, aerated static pile (ASP) facilities, or in-vessel systems. Composting is classified as a "green" technology by the US Environmental Protection Agency (EPA) because of its relatively low energy usage as well as the fact that compost indirectly helps store CO_2.

1.0 – COMPARISON OF COMPOSTING FACILITY TYPES

1.1 Aerated Static Pile Composting

Aerated static pile (ASP) composting is the most widely utilized method of composting biosolids. The ASP method of composting utilizes a series of permanent or disposable perforated pipes at the base of a mix of the material to be composted. These pipes are connected to a blower which supplies oxygen to the microbes which breakdown the material to be composted. The blowers can be attached to blow air through the pile (positive aeration) or pull air down through the pile (negative aeration). In addition to supplying oxygen to the pile the air removes water which dries the composting mass. Because the composting process is exothermic the composting piles heat during the composting phase and kill all pathogenic organisms. The U.S. Environmental Protection Agency (USEPA) 40CFR Part 503 regulations require that the temperatures in a compost pile which contains biosolids maintain 55^{o}C for three consecutive days for the ASP process (Class A). Because biosolids and to a lesser extent foodwastes are generally wet, contain free ammonia, and are too dense to allow air to flow through a pile the biosolids are mixed with another organic material called a bulking agent. The bulking agent can be yard wastes, wood chips, straw or similar materials. The bulking agent supplies carbon to the microbes thereby limiting the loss of ammonia, provides structure to the pile, and absorbs excess moisture.

Once the bulking agent and biosolids or food wastes or both are mixed the material is placed on top of a layer of wood waste or brush which covers the aeration pipes the mix is generally placed on top of the pipes to a height of six to eight feet by a front end loader (FEL). The mix is then covered with an insulation blanket of 12 inches of chipped brush, finished compost, or other material to keep the heat in the pile as well as keep moisture out. After building the pile it is left undisturbed for 21- 30 days. After this active composting period the pile can be torn down and screened. The finished compost is then allowed another 60 to 90 days to finish curing before it is sold or otherwise utilized.

When the pile is operated in the negative mode it is possible to treat the odorous gasses which can form during biodegradation of biosolids or food waste. These odorous gasses can easily be treated in a biofilter of scrubber. Because of this characteristic ASP is generally considered to produce the least odor of the three compost methods, other advantages of ASP composting include utilization of non specialized equipment, small area required to implement the process, ease of implementation, relatively low capital and operating costs unless the process is carried out in an enclosed building.

1.1.1 Aerated Static Pile Composting with Covers

A relatively new modification of ASP composting is to utilize tarps to cover the piles during the active compost period. The theory of compost covers or tarps is to limit the amount of moisture entering into a compost pile while at the same time limiting the emissions from the pile into the atmosphere. There are a number of compost cover vendors providing not only the tarps but also tarp handling equipment and auxiliary services. Some of the vendors such as Gore-Tex will not provide only covers but insist on engineering the aeration system as well. The tarps come in a large variety of fabrics and vary in effectiveness as well as durability and ease of handling. Tarps have been shown to reduce volatile organic carbon (VOC), methane, N_2O, emissions by 100 per cent. The tarps can also provide better moisture control which can also speed up the compost process.

Compost covers will reduce greenhouse gas emissions, improve water management, and reduce odor emissions while increasing operational costs to place and remove the covers. The tarps have a moderate capital cost and need to be replaced periodically.

1.2 Windrow Composting

Windrow composting is the most widely method used for composting yard wastes and agricultural wastes although it is also widely utilized to compost biosolids and food wastes with bulking agents. With windrow composting the material to be composted is mixed with a bulking agent and placed in a long pile called a windrow. Usually a front end loader is utilized to build the windrow and either a windrow turner which straddles the pile or a FEL is used to turn the pile. The height of the pile is limited by the reach of the FEL or size of the windrow turner. Windrow piles are generally 6 feet or less in height to maximize air movement through a pile. Air is provided to the organisms which break down the organic materials during the turning and to a lesser extent by convective action through the pile surfaces especially as the pile heats up.

In windrow systems that handle biosolids, the USEPA 40 CFR Part 503 Regulations require that the temperature of the compost pile be maintained at 55^{o}C or higher for 15 days or longer because there is no insulation layer and because of the large heat loss through the pile surface (Class A). During these 15 days there must be a minimum of 5 pile turnings. The windrows are usually in place for 30-45 days before they are broken down and screened and then they are cured as with the ASP method of composting.

The advantages of windrow composting are that it is easy to implement, can use readily available equipment, i.e. a front end loader, is the lowest cost operationally, and from a capital cost perspective. The disadvantages are that it has the highest odor generation capacity, is harder to meet 40 CFR Part 503 regulations, especially in inclement weather and takes up the most land area.

1.3 In-Vessel Composting

In- Vessel Composting follows the same principles as for either the ASP or windrow method of composting except it is done in some sort of enclosure and generally has more mechanization. Because the composting is enclosed the USEPA Part 503 biosolids regulations for pathogen kill are the same as those for ASP composting i.e., 3 days at 55^{o}C. The following sections briefly describe the major types of enclosed systems.

In general enclosed systems have the advantage of being more publicly accepted, because they are out of the view of the public and can have odor control. The disadvantages of enclosed systems are high capital and operations cost, complexity of operation, and specialized training required.

1.3.1 Container Composting

Composting containers are modular roll off containers with in floor aeration systems. The can vary in size but generally have 40 to 50 cubic yards of composting capacity. There are at least four vendors with multiple systems in operation on biosolids. The compost containers can be easily attached to a biofilter for odor and VOC emission control. The container manufacturers also sell auxiliary equipment to control aeration and load and unload the containers.

1.3.2 Tunnel Composting

The tunnel system is similar to container systems in that the composting is performed in an enclosed container with a built in aeration floor. The main difference is that the tunnel systems are generally significantly larger and more capital extensive. Tunnel composting is widely used in Europe for mushroom and source separated organics composting. There are several European vendors with experience in this technology. There is one tunnel system composting biosolids in the U.S. This system is the Cassel Hawk Ridge Compost Facility in Unity, Maine. Due to the high capital costs of installing a compost tunnel it is generally utilized for the initial stage of composting with curing done either in a building or out of doors.

1.3.3 Agitated Bed Compost Systems

Agitated bed compost systems are widely utilized for biosolids and food waste composting in the U.S. The system has aspects which make it similar to a combination windrow and aerated static compost system. With agitated bed systems the composting occurs in a series of trenches which have aeration systems at the base. The biosolids/foodwaste/bulking agent mix is added at the front of the trench and an agitator/turner moves the mix down the trench on a daily basis. The trenches are enclosed in a building and all building off gasses are collected and scrubbed through a biofilter or other odor control technology. Again because of high capital cost the agitated bay systems are generally sized to handle only the initial stages of composting with curing done either outside or in an enclosed facility.

Agitated bed compost facilities are capital intensive and power intensive, since all building off gasses rather than just process gasses are collected.They are operationally difficult to maintain since specialized agitator/turner equipment needs to be maintained in addition to the regular moving stock at the existing compost facility.

2.0 – MATERIALS BALANCE

The materials balance is one of the key tools in sizing a composting facility. If the mass balance is correctly formulated, then when storage times are known, it is possible to determine size for each component of a composting facility. For the materials balance to be accurate, it is important to know or have reasonable estimates of the solids (moisture) content, volatile solids and bulk density of the biosolids, food waste and yard wastes used in the composting process. In this section of the report each feedstock will be discussed separately.

2.1 – Biosolids

Oberlin produces approximately one dry ton per day of biosolids. The biosolids are digested and then processed by a belt filter press to a solids content of 19-23% in the winter and in the summer the biosolids are dried in a drying bed to a solids content of 40- 50%. Parameters which are important to determining the materials balance are described below as well as the reasons for their importance.

2.1.1 – Biosolids Solids Content

The biosolids solids content is important because the wetter the biosolids, the more bulking agent is required to produce a compostable mix of 38 to 40 percent solids. This is true for bulking agents of any solids content. Since aeration rates are based on cubic feet per hour per dry ton of material, the design of the aeration system and electrical requirements related indirectly to the solids content of the biosolids. For example, if the biosolids were 30 percent solids instead of 19 - 23 percent solids, less bulking agent would be required, and the proportion of biosolids per unit of volume would increase, so the aeration requirements would also increase. In general, the lower the solids content of the biosolids, the more volume (site space) and less aeration required, while the reverse is true as the solids content of the biosolids increases. To be conservative the wettest biosolids content of 19% solids will be used in determining the materials balance for Oberlin

2.1.2 – Biosolids Volatile Solids Content

The biosolids volatile solids content is important for two reasons. In general, the higher the volatile solids content, the more energy in the composting matrix and the more heat released. In order to keep the compost at optimal temperatures, it is necessary to provide more aeration to cool the piles. With wet biosolids, this extra oxygen demand is offset by the increased volume of bulking agent, which has a significantly lower oxygen demand.

The second reason it is important to know the volatile solids content of the biosolids is to estimate the volume loss between composting and curing. The higher the volatile solids content, the more biosolids will be degraded and the bigger the difference between input mix and composted mix. For purposes of design, a volatile solids content of 65 percent is assumed.

2.1.3 – Biosolids Bulk Density

The biosolids bulk density is a key factor because it translates into the volume of biosolids produced per unit of mass of biosolids (i.e., it tells the cubic yards of biosolids per wet ton processed). This volume determines size of biosolids storage, amount of material to be mixed, amount of material to be transported to a compost pile, and volume of space taken up in a compost pile. The higher the bulk density, the more weight per unit volume and the less space materials take.

The maximum density that biosolids could have is the density of water (1,685 pounds per cubic yard). Since most biosolids are slightly neutral in density (i.e., they float), the solids component of biosolids is lighter than the 1,685 pounds per cubic yard. The biggest factor in lowering the bulk density of the biosolids is the amount of air entrapped during the dewatering process. To be on the conservative side (maximize space requirements), a bulk density of 1,500 pounds per cubic yard will be assumed for this design.

2.2 –Yard Wastes

At the present time, Oberlin provided data on the amounts of leaves, curbside (compostable bag), and brush collected. The characteristics of the yard waste vary over time and are a function of the ambient weather conditions, composition of the yard waste, and age of the material. The yard waste materials are received from April to the end of the year. Since biosolids and foodwaste are processed year round it will be necessary to store the yard wastes until they are required to process the biosolids and foodwaste. It is assumed that there are 260 working days per year so the total yard wastes are divided by 260 to determine the amounts available daily for the materials balance.

2.2.1 –Yard Waste Solids Contents

As with the biosolids, the wetter the yard waste (bulking agent), the more required to bring the compost mix down to the required 38 to 40 percent mix. Because of seasonal variations in the bulking agent, it may be necessary to vary the ratio of bulking agent to biosolids during the year. In developing the materials balance a reasonable worst case in bulking agent solids content will be used to allow for changes in bulking agent in the future. For design purposes, it is recommended that a 60 percent solids bulking agent be utilized. This is an assumed average between the brush wastes and leaves. It is recognized that in the early fall the solids content will be higher and in the summer it will be lower. The only potential down side to using the bulking agent with lower solids content for design purposes is that if the bulking agent is drier and a lower ratio is used, then more biosolids will be present in the mix, and more aeration will be required. This could potentially require that smaller piles be built so that sufficient aeration can be provided per unit length of the pile. The same amount of biosolids would still be able to be processed since a smaller ratio would offset the lower pile height.

2.2.2 – Bulking Agent Volatile Solids

With low volatile solids biosolids, especially when wet and in winter conditions, it is necessary for the bulking agent (in this case yard waste) to supply some energy in the form of volatile solids. While woody material is very high in volatile solids (95 to 98 percent), most of the volatile solids are in unavailable or slowly available forms, such as cellulose and lignin. Fresher yard waste generally contains more highly available volatile solids and, therefore, is a better bulking agent for those months when composting is most difficult. Because a relatively small amount of the volatile solids is degradable during composting, the impact on volume loss is also minimal between composting and curing. Compared to biosolids, aeration rates for the bulking agent are minimal. For purposes of design, 73.6 percent volatile solids content is assumed.

2.2.3 –Yard Waste Bulk Density

As with all bulk densities, the lower the bulk density of the material, the more area per unit of weight at a given height is taken up. The smaller and more uniform the ground bulking agent, the higher the bulk density since more of the larger air-filled holes are eliminated. Likewise, the wetter the yard waste, the higher the bulk density of the material. In general, yard waste bulk densities of 400 to 600 pounds per cubic yard are very common.   Oberlin provided a bulk density of 500 pounds per cubic brush, a bulk density of 202.5 pounds per cubic yard waste collection and a bulk density of 350 pounds per cubic for leaves. A weighted average of 365 pounds per cubic yard based on 2011 data will be used for design purposes. This should allow for flexibility if future changes in bulking agent are desired.

2.3 –Food Wastes

At the present time, the only food waste information Oberlin provided was for food wastes at Oberlin College. The report provided stated that food collected from 12 sources around the campus amounted to between 1,400 and 1,500 pounds per day. It is assumed that this will not be a steady state number since colleges shut down for holidays and summers. However, this amount will be used for design purposes.

2.3.1 –Food Waste Solids Content

A total solids content 0f 23.5% was determined for the food waste during an analysis undertaken in September, 2012 This number will be used in the materials balance.

2.3.2 –Food Waste Volatile Solids

The same analysis cited above indicated a volatile solids of 95.465 however the analysis noted a range of 85-90% given the inclusion of paper wastes and other inerts. Volatile solids of 85% will be used in the materials balance. The lower volatile solids will mean that more compost will remain and more space will be required for curing and storage

2.3.3 – Food Waste Bulk Density

The Oberlin report gave no information on bulk density of the food waste however given that the water content is similar to that of the biosolids a similar bulk density of 1,500 pounds per cubic yard will be used.

2.4 – Input Mix

The ideal input mix should have a mix solids content of 38 to 40 percent and a bulk density of below 1,100 pounds per cubic yard. This mix will have sufficient porosity to allow for aeration with a relatively low headloss so that aerobic conditions can be maintained for ASP composting and good convection can occur with windrow composting. Windrow composting can generally start out wetter than ASP composting since water is lost as steam every time the pile is turned unless it is raining when the pile is turned. The mix is obtained by having the correct ratios of biosolids to bulking agent to achieve the desired result.

2.5 – Unscreened Compost

It is assumed that 15 percent of the input volatile solids will be degraded during the initial compost process. This amount of degradation is routinely achieved at biosolids, food waste, and yard waste composting facilities. The percent degradation would be higher if the percent grass and leaves in the ground yard waste were high and lower if the bulking agent were an aged wood product only. It is also assumed that the solids content of the cured material will be increased to 60 percent after the initial compost period. This 60 percent figure will allow for relatively easy screening and minimal dust formation. The bulk density of the composted mass will be 600 pounds per cubic yard or less.

2.6 – Biosolids/Food Waste/Yard Waste Materials Balance

Table 2-1 provides a materials balance using the assumptions from the previous sections of this report. In the materials balance for biosolids/yard waste/food waste there was insufficient yard wastes available to meet the composting criteria in paragraph 2.4 above so it was assumed that additional wood chips would need to be obtained, at least during winter conditions when the biosolids are wetter.

Table 2-1 Oberlin Materials Balance for Biosolids/ Food Waste/ Yard Waste

Feedstock	***Total Solids (%)***	***Volatile Solids (%)***	***Wet Tons***	***Dry Tons***	***Bulk Density (lb/yd^3)***	***Volume (yd^3)***
Biosolids	19	65	5.2	1.0	1500	6.9
Food Waste	23.5	85	0.75	0.2	1500	1.0
Yard Waste	60	74	1.6	1.0	365	8.6
Recycle/ New Bulking Agent	60	70	4.9	2.9	650	15.0
Input Mix	41	60	12.45	5.1	877	28.4a
Compost Loss				0.8b		
Uncured Compost	60	65	7.2	4.3	600	24.0
Recycle	60	70	4.9	2.9	650	15.0c
Compost	60	57	2.3	1.4	600	9.0

[a]Assumes 10 percent consolidation on mixing

[b]Assumes 15 percent volatile solids loss

[c]Assumes 80 percent of recycle and 30% yard waste recovered make up as needed with dry brush trimmings

2.7 Food Waste/Yard Waste Materials Balance

Table 2-2 shows a materials balance for just the food wastes and yard waste currently collected in Oberlin. You will note that no additional woodchips are needed to compost the combined food waste and yard waste streams.

Table 2-2 Oberlin Materials Balance for Food Waste/ Yard Waste

Feedstock	***Total Solids (%)***	***Volatile Solids (%)***	***Wet Tons***	***Dry Tons***	***Bulk Density (lb/yd^3)***	***Volume (yd^3)***
Food Waste	23.5	85	0.75	0.2	1500	1.0
Yard Waste	60	74	1.6	1.0	365	8.6
Input Mix	51	76	2.35	1.2	546	8.6
Compost Loss				0.1b		
Uncured Compost	60	65	1.8	1.1	600	6.0

[a]Assumes 10 percent consolidation on mixing

[b]Assumes 15 percent volatile solids loss

3.0 Advantages and Disadvantages of Utilizing Biosolids in the Compost

The primary advantages of utilizing biosolids in the compost mix are as follows:

- Biosolids has a comparatively high nitrogen content which can enhance the nutritive value of the compost
- The more material composted at once the lower the unit cost since equipment and labor can be amortized over more tons.
- There is a significant cost in handling biosolids presently so some of that cost could be utilized to offset lower cost of just composting food and yard wastes.

The primary disadvantages of composting with biosolids are as follows:

- Compost will not be considered "Organic" so cannot be marketed to organic farmers, etc.
- Must keep 40 CFR Part 503 records and do costly analyses. However depending on the proposed use of the compost it would be advisable but not mandatory to do at least some of the analyses.
- Higher potential for odor generation although this can be controlled
- Will require a supplemental bulking agent source which could cost money to purchase.
- Public perception of compost produced with biosolids can be lower than for compost from yard waste and food only.

4.0 Recommendations

If biosolids are included in the compost mix then ASP composting would be the method of choice. If the composting were to be done out of doors, then a covering tarp of some type should be evaluated. The reason that this technology was chosen is that it is easily scalable depending on the dewatering schedule, and most able to meet the USEPA requirements. It is also able to meet peaking requirements by adjusting pile heights.

If biosolids are not included in the compost mix, then windrow composting utilizing a front end loader would be recommended. If more environmental control is desired, bin composting should be evaluated as well. The capital cost should not be too great considering the small volume of material to be composted.

5.0 Use of Landfill Heat

There are two areas where the use of waste heat could prove beneficial to the compost process. The first way is applicable to ASP biosolids composting. The waste heat could be blown into the composting mass. This would allow more moisture to be driven from the pile and allow a slightly wetter mix which would reduce the bulking agent requirements.

The second area would be to maximize the beneficial use of the compost and the carbon footprint. This method would entail using the waste heat and plastic houses to grow plants year-round. Compost is a good carbon sink as well as a good growth medium for plants due to its nutritive and water holding properties. To maximize the beneficial properties of compost one should grow as many plants as possible. The plants absorb CO_2, a greenhouse gas, and produce O_2, a non-greenhouse gas. The use of the excess landfill heat in plastic houses will allow for year round plant growth and thus reduce the carbon footprint to the fullest.

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