To: Core Area Wastewater Treatment Project Board
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Reference: CRD Core Area Wastewater Treatment – Gasification Technology

The purpose of this white paper is to provide background information on the gasification process as it relates to the management of the residual solids that will be produced by the proposed liquid treatment facilities in the CRD. The proposed liquid treatment facilities will produce approximately 30 dry tonnes per day of residual solids at the average dry weather flow (ADWF) design condition of 108 MLD. The white paper will review the history of biosolids/ residual solids gasification and the potential for its use by the CRD. The paper also reviews the potential use of gasification using MSW and biosolids as a feedstock.

BACKGROUND

The technology of gasification first saw large scale use in the 19th Century converting coal into synthetic gas burned in lamps for light. The technology is still used to gasify coal as well as wood, agricultural waste, and other dry high energy value materials. Gasification of alternative feedstocks, such as biosolids, is a more recent development that has presented mixed results and operational challenges, and its operation is more complex than other processes typically used for biosolids processing. Gasification is a complex thermo-chemical process that breaks down compounds in the feedstock and reforms the elements into combustible gases (methane, carbon monoxide and hydrogen) and char. Non-volatile components of the feedstock will be left over at the end of the gasification process and are removed as ash.

In general, the gasification process can be broken down into three stages:

1. **Heating or Combustion (Oxidation)** – Typically heat is supplied by combustion of a portion of the feedstock material, but it can also be accomplished by using an external heat source such as an induction heater or a plasma torch. Combustion is achieved by supplying oxygen to the reactor. Oxygen is commonly supplied via air at approximately 20-30 percent of the amount required for complete feedstock combustion.

2. **Pyrolysis (Volatilization)** – In this stage, volatile compounds are broken down to carbon solids. The pyrolysis reactions are highly endothermic and require a large heat input in order to proceed. These reactions occur between 400°C and 700°C and proceed in the absence of oxygen, in contrast to Step 1.

3. **Gasification (Reduction)** – Elements are reformed into synthetic gas (syngas). This generally occurs between 850°C and 1,200°C. The type of gasifier used and the feedstock composition (e.g., digested or undigested solids) will impact the energy value of the syngas produced. Typical air-blown gasifiers will produce a relatively low energy syngas.

There are a wide variety of gasification reactors available and these can be divided into general gasifier types. **Table 1** lists the various general types of gasifiers and some of their characteristics. One type of gasifier that is not included in this list is the rotating drum gasifier with induction heating as manufactured in Germany by Pyromex.

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Table 1: Common Gasifier Types[1]

Gasifier Type	Scale	Fuel Requirements		Efficiency	Gas Characteristics	Other Notes
		Moisture	Flexibility			
Downdraft Fixed Bed	5 kW_{th} to 2 MW_{th}	<20%	· Less tolerant of fuel switching · Requires uniform particle size · large particles	Very Good	· Very low tar · Moderate Particulates	· Small scale · Easy to control · Produces biochar at low temperatures · Low throughput · Higher maintenance costs
Updraft Fixed Bed	<10 MW_{th}	up to 50% - 55%	· More tolerant of fuel switching than downdraft	Excellent	·Very high tar (10% to 20%) ·Low particulates ·High methane	· Small and medium scale · Easy to control · Can handle high moisture content · Low throughput
Bubbling Fluidized Bed	<25 MW_{th}	<15%	· Very fuel flexible · Can tolerate high ash feedstocks · Requires small particle size	Good	·Moderate tar ·Very high in particulates	· Medium scale · Higher throughput · Reduced char · Ash does not melt · Simpler than circulating bed
Circulating Fluidized Bed	A few MW_{th} up to 100 MW_{th}	<15%	· Very fuel flexible · Can tolerate high ash feedstocks · Requires small particle size	Very Good	·Low tar ·Very high in particulates	· Medium to large scale · Higher throughput · Reduced char · Ash does not melt · Excellent fuel flexibility · Smaller size than bubbling fluidized bed
Plasma	<30MW	any	· Greater feed flexibility without the need for extensive pretreatment · solid waste capability	Very Good	· Lowest in trace contaminants; no tar, char, residual carbon, only producing a glassy slag	· Large scale · Easy to control · Process is costly · High temperature (5000°-7000°F)
Liquid Metal	<7MW	<5%	· Generally requires low moisture due to the possibility of steam explosion	Very Good	.Low trace contaminants; virtually no tar, char, residual carbon	· High syngas quality
Supercritical Water	UNK	70 - 95%	· Suitable for the conversion of wet organic materials	Good	· Suppressed formation of tar and char	· Short reaction time · High energy conversion efficiency by avoiding the process of drying step · Selectivity of syngas with temperature control and catalysts

1. Roos, C., 2008. Clean Heat and Power Using Biomass Gasification for Industrial and Agricultural Projects. *U.S. DOE Clean Energy Application Center*. WSUEEP08-033, Rev. 5.

RESIDUAL SOLIDS/BIOSOLIDS GASIFICATION EXPERIENCE

Of the gasifier types listed in **Table 1** and the Pyromex rotating-drum type, only the following have been used to gasify residual solids from wastewater treatment facilities:

- Downdraft fixed bed
- Updraft fixed bed
- Fluidized bed
- Induction heated rotating reactor

Of these reactor types only the fluidized bed gasifier is still currently in operation for gasifying residual solids / biosolids. There have only been a handful of commercial-size biosolids gasifiers and a few bench-scale pilots. **Table 2** summarizes sludge/biosolids gasification commercial operations and their associated gasifier type, capacity, and current operational status. Note that most of the listed facilities were only operating for a short period of time or only conducted intermittent trials with a small shipment of sludge/biosolids. Many of the gasifiers had to be shut down due to operational problems.

Table 2: Summary of Full Scale Biosolids Gasification Facilities

Project Owner	Location	Gasifier Type	Capacity (Maximum)	Operations Status
Full-Scale Installations				
EcoTech Gasification (private developer)	Philadelphia, PA	Downdraft Fixed Bed (Primenergy)	Approximately 1.8 dry tonnes/hr	Started June 2005, currently not operating vendor no longer in business
MaxWest Environmental Systems, Inc	Sanford, FL	Originally Updraft Fixed Bed, converted to fluidized bed in 2012	0.6 dry tonnes/hr	Fall 2009 began operations currently not operating vendor no longer in business
MaxWest Environmental Systems, Inc	Plymouth, ME	Fluidized Bed	1.3 dry tonnes/hr	Project dropped vendor no longer in business
Kopf (demonstration facility)	Balingen, Germany	Bubbling fluidized bed	0.11 dry tonnes/hr Upgraded to 0.22 dry tonnes/hr in 2010	Started 2002, rebuilt in 2010, still in operation

Project Owner	Location	Gasifier Type	Capacity (Maximum)	Operations Status
Kopf (commercial installation)	Mannheim, Germany	Bubbling fluidized bed	0.57 dry tonnes/hr to be expanded to 1.14 in the future	Began commissioning phase in 2010
Tokyo Bureau of Sewerage	Kiyose, Japan	Circulating Fluidized Bed	Approximately 0.75 dry tonnes/hr	Started in July 2010, presumed to still be in operation
PHG Energy	Covington, Tennessee	Updraft Fixed bed	10 tons/day wood waste 2 tons/day biosolids	Under construction

Assuming no anaerobic digestion prior to gasification, the CRD would require a facility that could process between 1.1 and 3.2 dry tonnes/hr. With anaerobic digestion, the CRD would require a facility with a capacity of approximately 0.5 to 1.6 dry tonnes/hr, although this would reduce the energy content of the biosolids prior to gasification and could make operation of the gasifier more difficult.

Facilities summarized in Table 2 have used both digested and undigested biosolids. Of the facilities constructed, none could meet the raw sludge production rate for CRD and only the EcoTech facility in Philadelphia (which is no longer in operation) was large enough to meet the digested sludge production rate. The three operating viable commercial operations were the MaxWest facility in Sanford, FL (not currently operating); the Kopf facility in Manheim, Germany; and the Tokyo Bureau of Sewerage facility in Kiyose, Japan. A more in-depth review of these three operations is provided in the following sections, in addition to a description of the M2R/Pyromex gasifier.

ECOTECH (PHILADELPHIA FACILITY)

The EcoTech facility was a private commercial venture to process wastewater treatment plant (WWTP) sludge and water treatment residuals. The facility dried sludge prior to sending it to the downdraft gasifier. Syngas from the process passed through a cyclone to remove particulate and was combusted. Heat from the combustion was used to run the dryer and generate steam for power generation. Waste steam generated was used back in the gasifier.

From discussions with personnel involved with operations of the facility the following issues led to the failure of the facility:

- The WWTP sludge was first digested and the energy value of the material quality fluctuated because of digestion and the addition of the water treatment residuals. The power generation is not known but it is suspected to be very low given the experience at other facilities and the typically low energy value of syngas from air blown gasifiers.

Reference: CRD Core Area Wastewater Treatment –

- Both the water and wastewater solids contained ferric chloride and this increased particulate and slag generation. Frequent slag generation in the heat exchanger caused the system to shut down for cleaning as often as every two weeks. Slag generation can occur when temperatures exceed the ash melting point of the feedstock (approximately 1,000-1,100°C), and careful operations control is required to maintain temperatures in an optimum range.

MAXWEST (SANFORD, FL FACILITY)

Several modifications have been made to the Sanford facility since it first began operation. These include replacing the existing batch indirect rotary dryer with a continuous flow indirect dryer, replacing the fixed bed gasifier with a fluidized bed unit, and adding a cooling tower to the air exhaust stack. In the MaxWest process, undigested dried sludge is gasified in the fluidized bed reactor and the syngas is passed through a cyclone to remove particulates. The gas is then combusted in a thermal oxidizer to heat oil for operation of the indirect dryer. The combustion of the syngas immediately downstream of the gasifier reduces the requirements for syngas cleaning, which would be required for use in an internal combustion engine. Exhaust from the thermal oxidizer passes through a cooling tower before going out the facility stack. The cooling tower is needed because the facility is in the flight path of a nearby airport and the uncooled exhaust had the potential to create turbulence. The original facility had no emissions controls, however, subsequent exhaust sampling has showed that NO_x and HCl concentrations are above allowable limits and reduction controls are needed.

It is worth noting that there was no power generation from the syngas at the Sanford facility. All of the energy generated in the form of heat was used in the dryer. In this type of system, the energy balance is highly dependent on the upstream sludge dewatering processes since it is more cost-effective to remove water mechanically (through thickening/dewatering) than through thermal drying. For example, the Sanford facility required natural gas to supplement the energy needs of the dryer, though the system had the potential to become energy neutral during normal operations by dewatering to a higher solids concentration upstream of the dryer.

KOPF (GERMANY FACILITY)

In both the Balingen and Mannheim, Germany facilities the drying operation occurs separately and the gas produced is used to produce electricity. This requires additional syngas cleaning steps relative to the use of a thermal oxidizer downstream of the gasifier, as in the MaxWest system. Although Kopf has a patented gas cooler step for tar removal, the overall technology for this type of gas cleaning is not considered fully developed. Kopf has also noted that the performance of their gasifier appears to be extremely sensitive to the type of dryer used and the subsequent characteristics of the dried sludge feedstock. The general process steps are described below.

The dried biosolids are gasified in a fluidized bed reactor. The syngas passes through a heat exchanger that warms air going into the gasifier. The gas is then cooled with a water quench that also preheats the biosolids going to the gasifier. The gas then passes through a baghouse and then to a condensate cooling/drying step. It is then burned in a combined heat and power (CHP) generator to produce electricity and recover heat. There is condensate generated in the cooling process that must be treated in the WWTP. The facility produces approximately 636 kW per dry tonne of sludge processed. Approximately 21% of the power produced is used to run the process, excluding the dryer operation.

TOKYO BUREAU OF SEWERAGE

The Tokyo Bureau of Sewerage operated a sewage sludge gasification pilot plant from 2005 to 2006 (approximately 3,400 hours of operation) at the Kiyose Water Reclamation Plant. Based on the results of this pilot study, the Tokyo Bureau of Sewerage has reported that a full-scale system was constructed which began operation in July 2010. At this time there is very little published information about the full-scale facility. The system processes dried sludge using an internally circulating fluidized bed gasifier. The syngas is processed through a heat exchanger to heat the recycled preheating gas stream which is used for operation of the drying the sludge in the drying unit. Finally, the syngas is passed through a liquid scrubber and the syngas is burned in a gas engine. The syngas must be blended with a natural gas supplement (50/50 syngas to natural gas ratio reported for pilot operations) in order to successfully operate the gas engine generator (the energy content of the syngas by itself is relatively low). The full-scale facility is presumed to still be in operation. It should be noted that the objective of the Tokyo Bureau of Sewage was not to have net energy production but rather to reduce both their carbon footprint an d the use of natural gas.

M2R/PYROMEX

Pyromex does not have a current commercial facility; however, it is worth examining their process because it is significantly different from the MaxWest and Kopf processes. The primary difference is that the system uses an induction heater to supply external energy to heat the feedstock (in lieu of combustion of a portion of the feedstock). In the Pyromex process, the biosolids are dried and then processed through their rotating induction heated gasifier. There is no combustion step in the gasification process, and a nitrogen gas purge is used to keep oxygen out of the system. This results in the production of a higher energy syngas because the syngas is not diluted with nitrogen gas from the air and the there is no loss of volatile solids to combustion. As a result, the system can achieve a slightly higher power output, but electrical energy is also required to operate the induction heater. After gasification the syngas is cleaned and cooled in a similar manner to the Kopf process before going to a CHP generator. The reported power generation is 880 kWh/dry tonne of solids. Of this the gasification process uses 33% and the drying process uses 52% resulting in only 15% of the power generated available for sale or other uses.

PROCESS LESSONS LEARNED

Although different gasifiers can tolerate higher moisture contents in the feedstock material, efficiency generally decreases with increasing moisture content. Usually the minimum target solids content of the sludge going into the gasifier is about 85%+, though some water is needed in the feedstock in order for the water gas shift reaction to occur in the gasifier. The high required solids content means there must be a drying step prior to gasification of sewage sludge, which has comparatively higher moisture content even after upstream thickening/dewatering processes. The ability to generate electricity from the syngas hinges on whether the drying step is heated by the syngas or by another fuel such as natural gas or digester gas, and also depends on the solids concentration of the sludge entering the dryer (as noted above). Use of dryer higher energy material with the biosolids may reduce the drier load and improve energy output. This is currently being attempted at the PHG Energy facility in Tennessee. There is no operational information about this facility currently available.

If the dryer is dependent on syngas generation, there will not be enough electrical power generation capacity to warrant the cost of gas conditioning equipment and the system mainly becomes a disposal system that can power itself. This is often referred to a as a close-coupled (closed loop) gasification system and is similar to the MaxWest system described above.

The ash melting point of the feedstock materials is also crucial. If the gasifier runs above the ash melting temperature, slag can be generated and this will significantly increase cost of operation and decrease the productivity of the system.

The exhaust from combustion of the syngas requires treatment for NO_x and possibly for HCl. NO_x can be treated using either selective catalytic or non-catalytic reduction. The HCl can be treated with a wet to dry lime slurry scrubber.

The metals content of the ash will determine if it can be beneficially used or if it will have to go to special waste disposal. The ash can potentially be used for building products such as cement or other industrial uses for carbon solids. Phosphorus recovery from the ash is also possible but the technology is still in the development stages.

GASIFICATION AT THE CRD

The CRD has been examining several options for biosolids treatment and beneficial reuse. Of these options there are two that are compatible with adding gasification: the first is digesting and drying the sludge, the second is drying the raw residual solids without anaerobic digestion. **Figures 1 and 2** show the rudimentary process flow for each of these options with gasification added. It should be noted many process details and refinements are not shown.

Reference: CRD Core Area Wastewater Treatment –

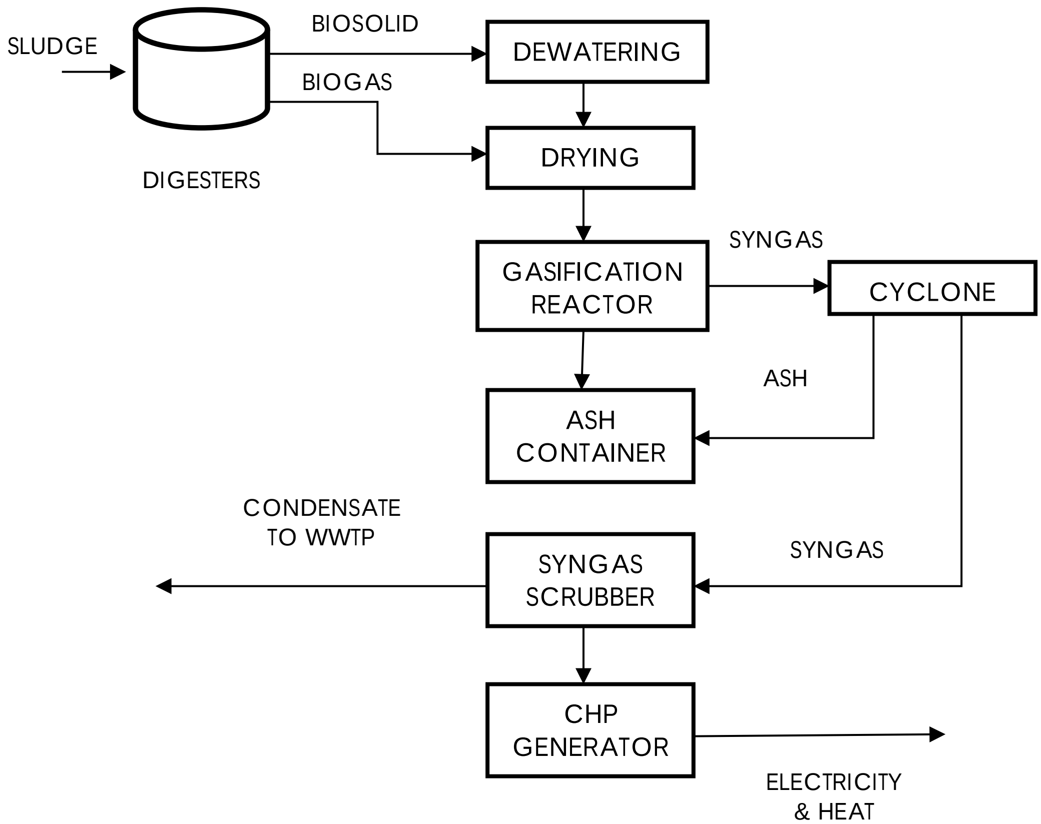

Figure 1: Simplified process flow for gasification of digested biosolids

Reference: CRD Core Area Wastewater Treatment –

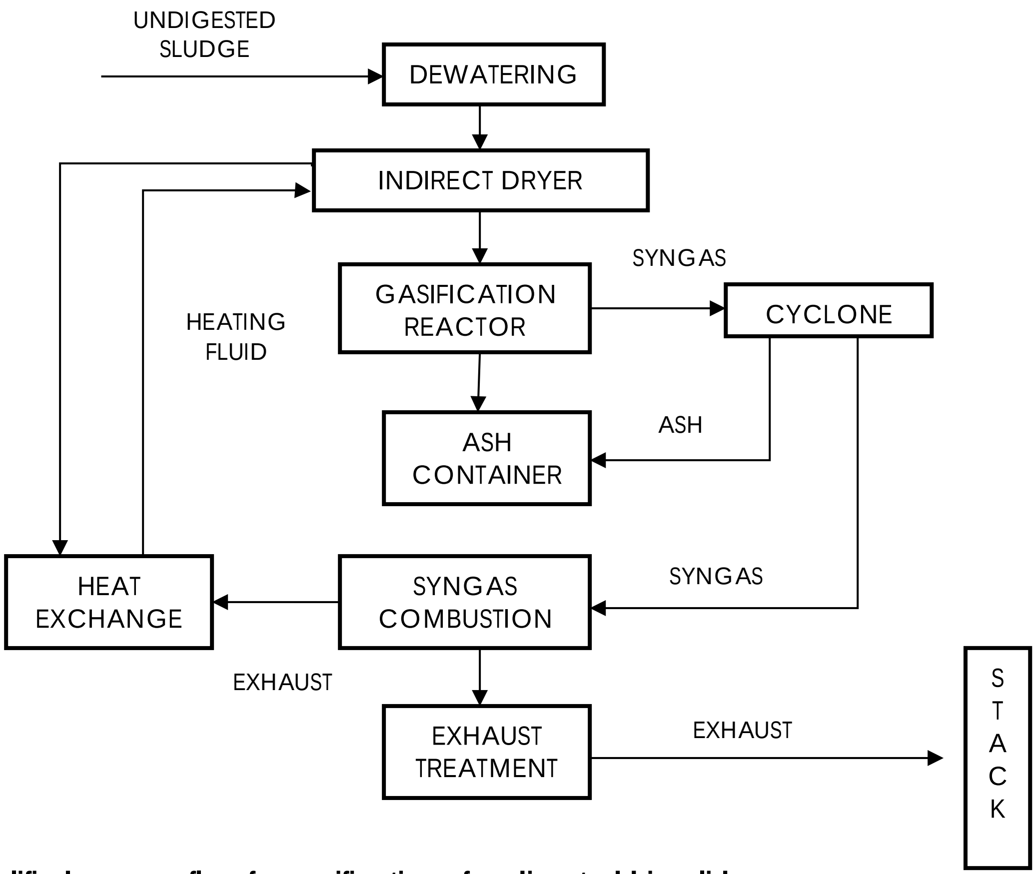

Figure 2: Simplified process flow for gasification of undigested biosolids

If residual solids are digested, biogas produced by the digesters would be used to provide heat for the dryers. The syngas from the gasification process could then be used to produce electricity. Without anaerobic digestion, the syngas is used to provide heat for the dryers, in addition to any natural gas supplemental fuel that may be required.

INTEGRATION WITH MUNICIPAL SOLID WASTE (MSW)

The CRD has expressed interest in potentially gasifying MSW with treatment facility sludge as part of an integrated waste management plan. This would be an issue for the gasifiers utilized for biosolids so far due to the heterogeneous nature of the character of Municipal Solid Waste (MSW). Different materials have different ash melting temperatures. The ash melting temperature is the point at which slag is generated. Slag in the gasifiers used to date for biosolids interferes with the gasifier operation and must be cleaned out. However, gasifiers utilizing plasma torches to generate heat have been developed to gasify MSW. In England the Tees Valley gasification facility was under construction to gasify MSW using plasma gasifiers. The facility was to consist of two gasifiers. The first gasifier was completed and operations begun with it while the second and third gasifiers were

Reference: CRD Core Area Wastewater Treatment –

constructed. However, the first unit was not successful and before completion of the second gasifier and investing close to a billion dollars the developer of the project abandoned the facility.

Several other locations are using gasification with multiple dry feedstocks including wood waste and other dry fuel feedstocks. The potential to use bisolids as a component of a multi-feedstock facility exists but should be evaluated on a case by case basis to determine the economics and operational impacts on such a facility. For CRD consideration of the technology selection for the MSW is essential to ensure reliable MSW disposal and the impact of biosolids addition to whatever technology is ultimately selected needs to be evaluated. This assessment could be completed as part of the MSW / Biosolids Integration planning.

If and when the technology performance and reliability improves in the future as a result of further technology refinement and longer term proven operating experience, the CRD could consider gasification as an add-on process for biosolids and MSW.

CONCLUSION

Successful use of gasification technologies for residual solids/biosolids processing is limited at this time. The performance of gasification on biosolids applications has met with mixed results and many of the facilities have had operational difficulties and have been shut down. The financial viability of the gasification of residual solids has not been proven and many of the developers have gone out of business. Other options such as incineration / waste to energy have a longer term operations track record and better reliability.

Gasification facilities are operationally complex. Although the technology shows promise, further refinement will be required to make it a viable and reliable option for long-term biosolids treatment. At this time we would recommend CRD not consider gasification as there is no long term proven track record for the technology at the scale required for the solids treatment facility. Given that the installations to date have met with mixed results, there is significant risk to the CRD by utilization of this technology.