Rapid Technology Assessment for Omni-Processor Project

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Submitted by

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1. Introduction & Background

The Bill & Melinda Gates Foundation (The Gates Foundation) is developing an Omni-Processor Project as part of its water, sanitation and hygiene efforts for developing countries. To more effectively target future information requests and technology investments, the Gates Foundation tasked Concurrent Technologies Corporation (CTC), an independent, nonprofit, applied scientific research and development organization, to identify and screen existing technologies and systems that may be applied to meet the objectives of this project. Because the Gates Foundation is interested in testing a working prototype as soon as reasonably possible, CTC's technology scouting effort primarily focused on commercially available technologies although some emerging technologies were also captured. This Rapid Technology Assessment Report documents the search methods, summarizes the results, and proposes next steps.

Treating human waste is a necessity, and much effort has been invested in efficiently and economically addressing this matter to mitigate net effects on human health and the environment. Typical residential sewage includes household wastes such as those generated from sinks, toilets, showers, and laundry activities. In developed countries, sewage is typically sent to a wastewater treatment plant where contaminants are removed from the wastewater. The treated water is discharged to a waterway (where it may be reused downstream) or more directly reused for agricultural, industrial or other purposes. The separated and treated solids are often also reused, for example, as farm fertilizer after drying. It may also be landfilled or injected underground where land application is prohibited.

Developing countries, lacking the infrastructure of modern waste handling and treatment systems, need another option for safely and cost-effectively processing human waste together with urban organic waste at a neighborhood level. While latrines and septic tanks are often common fixtures, the cost is very high for properly emptying them and transporting contents to a processing plant. Consequently, tanks often overflow or are manually emptied and contents dumped into nearby alleyways or waterways, presenting a health hazard. Collection and treatment of other organic wastes from urban residential living, such as food and other household garbage as well as abattoir (slaughterhouse) waste, also present challenges.

Through its Omni-Processor Project, the Gates Foundation is interested in evaluating cost-effective and sustainable solutions for the combined processing of fecal sludge and urban organic waste. The preferred solution would be free standing, have low capital and operating costs, be self-sustaining (generating the energy needed to operate), have no water or sewer requirements, be easy to operate and maintain, and have a small footprint. The Foundation defined a small footprint as consisting of a combined length and width of less than 3-6 square meters and a height less than 3 meters. This system would support 1,000-5,000 people in an urban setting and have a capacity of 0.5-5 tons of waste per day. Ideally, processed waste will be converted into products that can be re-used and generate revenue, thereby offsetting waste collection costs, encouraging technology acceptance and use, and increasing the countries' standard of living.

As detailed within this report, CTC did not identify any single technology that would fit the specifications called for by the Gates Foundation. Successful execution of an "omni-processor" concept is highly dependent on the modes of transporting waste to and from the processor and the close proximity of user(s) of the generated heat and/or power. Based on the technology scouting findings, CTC recommends the Gates Foundation focus its attention on anaerobic digesters that produce biogas, heat and fertilizer for waste streams like septic system waste that contains a high liquid content. Community anaerobic digesters have been used in the urban context of interest to the Foundation in India for many years.[i] Larger, commercial-scale operations have been part of wastewater treatment plants treating human sewage and have successfully treated biosolids for decades. The anaerobic digesters technology companies interviewed expressed an interest in continuing to invest in technology improvements.

If an acceptable footprint can be larger than the desired 6 square meters, a more complete conversion strategy would be the pairing of a small anaerobic digester and a small-scale gasifier. Micro-scale gasifiers can handle at least 25-50 pounds per hour of municipal solid waste (MSW), which has been preprocessed by shredding and densification. This hybrid system could handle all waste components of an urban center with the exception of noncombustible waste such as glass and metals as well as hazardous and medical wastes.

2. Technology Search Strategy

The technology search strategy was a rapid scouting of readily available databases and websites to help focus future efforts of the Gates Foundation. The four main steps included: (1) a broad search based on the problem statement, (2) application of the Gates Foundation criteria to the initial results to focus on a smaller subset of potential candidates, (3) focused searching for commercial organizations using anaerobic digesters, and (4) direct contact with commercial organizations with the most-promising technologies. The search strategy was not a comprehensive literature review or a comprehensive assessment of the whole wastewater treatment and/or energy technology industry. CTC's results present a snapshot of what is currently available for relatively mature technologies that can be used to address the problem of sewage management in developing countries.

The first step of the search strategy was to conduct a broad search for solutions to the problem understood as: (a) existing sludge in latrines and septic tanks, (b) lack of adequate sanitation in homes and villages, and (c) continuing sludge management problems if better latrine/septic systems are not used. The search strategy included using Boolean logic to search the deep web as well as in databases specializing in scientific and technology-related journals. The literature search focused on recent research, from 2008 to the present. Some older documents were included if they were particularly useful. Also, previous technology research for the Department of Defense on commercially available waste-to-energy (WTE) systems was leveraged. This first phase of the technology searching revealed solutions for improved toilets, methods for removing and transporting sludge, anaerobic digesters, and WTE for MSW. Results of this search were summarized in an Excel spreadsheet and are included in Attachment A, under the "Technology Search" tab.

The second step was to apply the selection criteria established through input from the Gates Foundation that the technology be able to: (a) segregate and process human *and* organic waste; (b) handle a throughput capacity of 0.5-5 tons per day for servicing 1000-5000 people in urban environments; (c) create a useful byproduct (heat energy, charcoal, biochar, soil improver, soil fertilizer, mineral ash, recovered water, etc.); and (d) be robust enough to operate under developing country conditions. Based on these criteria, anaerobic digestion for biogas production represented the most applicable technology solution for liquid septic tank waste. To further destroy the solids and handle non-biodegradable waste such as plastics, anaerobic digestion could be paired with a small-scale gasifier and preprocessing unit. Candidate gasifiers are listed in Attachment A under the "Small-Scale Gasifier" tab.

Based on initial findings, CTC narrowed its search and used OneSource, a proprietary database, to identify companies involved in the biogas industry. OneSource combines data from 2,500 sources to form a comprehensive resource to identify companies throughout the world. As explained more thoroughly in Section 3, Results, many of the identified technologies focus on human waste only, apply to individual households only, rely on farm waste, require power and/or water infrastructure, and/or have a large footprint.

The third step of the search strategy was to evaluate the approximately 100 biogas technology companies identified through OneSource. Companies that supply parts or manufacture individual components of biogas technologies were removed from this initial list. Municipalities that have a biogas process associated with their wastewater treatment systems but do not manufacture these digesters were also removed. This refined list included approximately 50 potential companies and organizations, which are listed in Attachment A, under the "Biogas Companies" tab. Additional research into these candidate organizations and technologies was performed to identify those most applicable to the urban context of developing countries, further reducing the candidate organizations to 19.

The final step was to contact the reduced list of most-promising organizations to attempt to obtain additional information on the system footprint, functional capabilities, performance and cost that was not available from the websites. A standard script was developed with an introduction and questions and was used when contacting the companies by phone, email or through online data request forms. Contact information was obtained through the organization websites. Few responses were received during the timeframe available to this project. The information received is summarized in Attachment A, under the "Down Selected AD Technologies" tab.

3. Results

The CTC search did not identify any technologies that fully met all of the desired characteristics expressed by the Gates Foundation. Explored technologies can be grouped into the following areas: WTE including anaerobic digesters, composting, and material processing. An overview of each of these groupings is presented in this section. Based on the initial findings, additional research was conducted on anaerobic digesters as discussed below. Although included in the spreadsheet found in Attachment A, methods for removing and transporting sludges are not discussed as they do not meet the Foundation's criteria for a waste treatment technology. However, they may be incorporated into the waste treatment process that includes the acquisition of the waste.

Overview of Available Technologies

Waste-to-Energy

WTE technologies harvest waste streams for their energy value and convert them into electricity, gas, or heat. The energy value is highly dependent upon the British thermal unit (BTU) content of the feedstock. For example, dry biosolids have about 6000-7000 BTU per pound (/lb), food waste has about 2500 BTU/lb, and MSW contains about 6500 BTU/lb.[ii,iii]

A generic WTE conversion process can be broken down into three general steps: feedstock conditioning, conversion into a fuel product, and power generation. Feedstock conditioning includes actions taken to improve the raw waste stream, including manual operations (e.g., sorting and segregation) and mechanical processes (e.g., shredding and densification). With conversion, prepared feedstock is transformed into a gaseous or liquid fuel product. Power generation includes the means by which the fuel product is converted into electricity, minimally to self-power the process, but ideally to generate a surplus that can be used to power other equipment or be supplied to a public grid. Basic WTE pathways include thermal (e.g., incineration and gasification) and biological (e.g., anaerobic digestion).

Thermal WTE Technologies

Thermal WTE technologies can handle many types of organic matter, including plastic, wood, and paper. Most cannot handle glass, metals, hazardous, medical, or radioactive waste. However, WTE technologies are best suited for wastes that do not contain more than 20% moisture. Wet wastes, such as food wastes, usually need to be dried prior to entry into the thermal unit or at least mixed with cardboard, wood, or other dry items to reduce the overall moisture level. Some WTE units, particularly incinerators, may accept wastes with moisture levels higher than 20%, but their fuel efficiency drops because the unit must use supplemental fuel such as diesel to dry the waste before it can combust it.

The simplest WTE technology is an incinerator that uses heat to generate hot water. Larger units can use the heat to produce electricity; however, this technology requires water if generating power with a steam turbine. Although today’s versions are more sophisticated, incinerators have been available for decades and are relatively easy to operate. Another thermal WTE type is a gasifier. Gasification itself is a mature technology, and many vendors offer gasification systems. However, other WTE types are relatively new and do not have a lengthy field history.

Gasifiers usually operate at temperatures between 1,400°F to 2,500°F (760°C to 1371°C) depending on the specific technology. Significant advancements have been made in the field of gasification, and several vendors are developing mobile units that treat 0.5 to up to 5 tons of waste per day. A few mobile gasifiers are commercially available or in the field validation stage. One advantage of these small throughput units is that after initial startup that requires a fuel source, many of these units are designed to be self sufficient and require no other utility support. However, most gasifier systems do not meet the Foundation criteria for footprint size. Even small mobile units require at least 20 feet in length, plus a staging area is required. Computer-automated operation requirements, such as those used by Community Power Corporation, can be complex, requiring well-trained operators. A few companies are now offering pallet-size gasifiers that better meet the Foundation's footprint requirement although they cannot handle up to 5 tons per day of waste. For example, the All Power Laboratory (APL) GEK Power Pallet is a complete 20 kilowatt (kW) system that fits into a 4- x 4- x 7-feet pallet. However, this system was designed to operate on biomass shredded to 1 inch. For these small-scale biomass systems to work with MSW, the waste must be shredded and densified by briquetting or pelletizing. Each system has its "sweet spot" when it comes to size of feedstock.

One disadvantage for thermal WTE units is the permitting process. Within the United States and other countries, air pollution permits are required for some systems due to potential hazardous air emissions even though abatement systems are incorporated into the systems. Depending on the system, personal protection equipment requirements may consist of safety glasses, hard hat, safety shoes, hearing protection, and other items. Another disadvantage is the high capital costs. Most of the small WTE units cost at least $500,000, and the majority are over $1 million. Micro-scale systems offer cost advantages with prices ranging from $20,000 to $100,000 for complete turnkey systems. Small-scale shredders and densification units would increase this cost by $50,000 to $100,000 depending on type of equipment selected.

Plasma gasification utilizes a plasma torch to assist the gasification process. These units are energy intensive and have not been found to be economical on MSW. Plasma units typically have the highest capital costs; the lowest CTC identified was at least $3.5 million. With their high energy demands for the plasma torch, plasma WTE technology is best suited for medical and hazardous wastes that are associated with potential implications to air quality and high alternative treatment/disposal costs.

Other thermal technologies include thermal depolymerization and pyrolysis. Thermal depolymerization by anhydrous pyrolysis is a method of converting waste into oil with the use of superheated and pressurized water. Pyrolysis is thermal treatment like gasification that uses a lower temperature and no oxygen and converts waste into a liquid oil and combustible gas stream. Thermal depolymerization and pyrolysis technologies are not commercially available to meet the needs of the Foundation due to size and utility requirements.

Biological WTE Technologies

In comparison to WTE technologies, biological WTE technologies operate at lower temperatures and have lower reaction rates. They can accept feedstocks with high moisture levels if they are biodegradable.

Anaerobic digestion is a biochemical WTE process that converts complex organic material, such as animal manure, into biogas, heat and fertilizer. Biogas is composed primarily of methane (60-70%) and carbon dioxide (30-40%) and has many possible uses including cooking, lighting and fuel.[iv] Sulfur constituents of biogas include hydrogen sulfide and mercaptans (ethyl and methyl) which can create odor.[v] If sulfur levels are low enough, the biogas does not need additional treatment for most applications, but if the gas is to be used in machinery that uses natural gas, it requires additional purification. The advantage of the digesters is that they provide a way to capture biogas for other uses while also decomposing waste for use as fertilizer. Digesters also produce heat that is typically returned to the process to enhance efficiency.

Anaerobic digesters have been successful at the industrial scale for large agriculture operations, community wastewater systems and other forms of solid waste management for urban areas. These systems are large scale with a large footprint, which enables the operation to be profitable. Even on these commercial-scale systems, many aspects other than biogas production must be incorporated to make a system profitable. Large farm-scale systems that utilize balloon-type covers over manure lagoons can be profitable on biogas production and liquid and solid fertilizer reuse. Other large-scale industrial systems are more for waste treatment than for biogas production, using the biogas mainly as a means to keep the reactor at temperature. Household-scale digesters have been in use for several decades with millions in use in China and India. Examples of community scale tend to be at schools or prisons where the source can be effectively controlled and the biogas readily used. Commercially available small-scale digesters are limited, as most small-scale systems are individually designed and pieced together to control costs.

Digesters can handle wet waste streams with no pre-treatment. They work more effectively with fresh fecal matter that has not already been decomposing in latrines, but they can still use these sources. Most digesters can handle an influent with a solids concentration of 2-15% total solids. Septic tank waste falls within this solids range. If the solids content of the waste is higher than this concentration level, then additional water may be required to dilute the influent. If the organic fraction of the MSW is to be added to the anaerobic digester, the total solids of the influent will have to be managed to keep it below 10%. The effluent liquid can be used to dilute the influent solids to minimize the use of water. The addition of MSW will also require a longer residence time for the solids within the digester.

A digester designed for an influent feed of 1 ton of wet waste per day would need to be a 10,000-15,000 gallon vessel. This estimate is based on a 20-day hydraulic retention time (HRT). The HRT is the ratio of the reactor volume in relation to the influent feed rate. This ratio determines the time the waste needs to be in contact with the biomass. The biomass in the reactor is controlled by the solids retention time (SRT), or the time the solids are in the reactor in relation to the amount of solids extracted from the reactor. SRT can be increased if more stability is needed within the reactor or to increase biomass levels.

Anaerobic reactors produce a liquid and a solid effluent in addition to biogas. The liquid effluent is suitable for a liquid fertilizer or can be further treated by aerobic means. The solid effluent can be further processed by aerobic composting and used as a soil amendment. This solid effluent could also be comingled with MSW and processed in a thermal WTE unit.

Anaerobic digesters usually operate at mesophilic (77-104^{o}F; 25-40^{o}C) or thermophilic (122-131^{o}F; 50-55^{o}C) temperatures. Thermophilic digesters operated at 131^{o}F (55^{o}C) have a nearly 100 percent reduction in pathogens such as helminth eggs.[vi] Together, the West Virginia Department of Agriculture and West Virginia State University demonstrated that a 10,000-gallon digester with a 10-day HRT successfully eliminates pathogens.[vii,viii] Their thermophilic digester operated at 131^{o}F (55^{o}C) and was designed by Dr. David Stafford of Enviro Control Limited of

Monmonth, England. This digester was designed to support microbial colonies by mixing with biogas and avoiding the introduction of air into the system.

From the Foundation's perspective, an advantage of the anaerobic digester technology is its maturity. Technology disadvantages are the need for frequent emptying of latrines for feedstock and the high upfront cost for the digesters and the gas delivery system. Also, biogas is generated under pressure, so systems must be monitored to manage the pressure and ensure removal of the biogas on a continual basis. Similar to thermal WTE technologies, anaerobic digesters offer a distributed power solution for urban communities. The biogas can be piped to areas of use or fed into power equipment such as internal combustion engines to produce electricity.

Composting

Composting is the aerobic decomposition of organic solids using micro-organisms, macro-organisms (e.g., worms and beetles) and/or fungi to produce a soil amendment for erosion control and other useful purposes. Active organisms feed on the organic materials in the solid waste material to build new molecules and release carbon dioxide, water vapor, and heat. A proper mix of materials is needed to promote the accelerated growth of microorganisms and, therefore, rapidly process the organics while reducing volume and odor and killing pathogens. If conducted properly, compost produced from these wastes can produce a stable product for unrestricted use. However, the compost market for developing countries may be too low to support a compost operation from an entrepreneur's perspective.[ix]

From a broad perspective, composting falls into two categories – aerated piles and in-vessel composting technologies. Aerated piles have the advantage of being fairly low cost and easy to operate, but disadvantages include the long time period, odors, need for aeration and a large footprint required for the piles to be composted. In addition, to transport the waste, a forklift is recommended to minimize heath issues during the handling of the feedstock.

In-vessel container configurations have the advantage of decreasing the time needed for composting, preventing vermin access to the decomposing waste, minimizing odors, and have a smaller footprint than aerated piles. However, the footprint size is still larger than the Foundation's requirements as a small in-vessel unit would likely be at least 24 feet by 8 feet wide. Furthermore, many of the self-contained units have high energy demands and high capital costs. Effective composting requires the correct mixture of carbon to nitrogen in the feedstock to perform effectively on a large scale. So, even though the technology is relatively simple, maintaining the correct mixture of wastes requires training and expertise. The disadvantage to applying composting technologies for use with human wastes is the need to provide high enough temperatures to destroy disease-causing pathogens.

Toilet Options/Sanitation

Composting toilets are miniaturized versions of in-vessel composting units. At the residential level, several composting toilet options are available. This technology is proven and eliminates the need for septic tanks. Many of the toilets are available with no or very minimal water and electrical needs. Prices are generally less than $2,000, with many vendors offering reduced prices for bulk purchases.

An advantage of composting toilets is that the waste is treated at the generation point, eliminating the need for removal and transportation before treatment. The compost material can be used as a soil conditioner. A disadvantage is the biogas generated is vented away rather than reused for energy.

Several composting toilet system projects have been initiated in developing countries. A project by Nepal SEEDS incorporated a composting toilet system with an anaerobic digestion system that could handle human waste as well as animal waste.[x] The two waste sources entered a larger tank through different sources and the biogas was then piped to kitchens for cooking use. Biogas composting latrines have also been used by others such as Engineers Without Borders (EWB) in developing nations.[xi] In addition, a variety of organizations have explored the implementation of communal latrines. As discussed in a 2011 paper titled Innovative "Sanitation as a Business" Model: CCS in Nairobi, Kenya, for some entrepreneurs, a public bathroom has become a revenue generator as people pay to use the facilities.[xii] According to the paper, many residents of low-income urban communities do not have access to a toilet and will pay to use a public facility.

While composting toilets are an alternative sewage treatment, they do not meet the Foundation's criteria for the Omni-Processor Project. This project was to find a system that supports up to 5,000 residents. Composting toilets do not satisfy that scale criterion; they are for individual homes or communal latrines. In addition, these solutions are typically not designed to compost other organic waste streams. Lastly, while an individual unit is low cost, the cost would be over $1.6 million to supply the toilets to a population of 5,000 people. This amount assumes a toilet can be obtained for $1000, and that each toilet services 3 people. It does not include installation costs. Although this technology does not meet the Omni-Processor Project requirements, vendor information is summarized in Attachment A under Compost Technologies because it may be of interest to the Gates Foundation related to its other water, sanitation and hygiene efforts for developing countries.

Material Processing

Material processing includes two related types of technologies—densification and sludge drying/dewatering. Densification and sludge drying technologies are approaches to removing water, mixing and pre-processing waste to reduce weight and volume in preparation for other disposal techniques such as WTE. Densification, for example, can reduce the volume of paper waste up to 75%. In industrial applications where waste volume, not weight, is the cost driver, the primary advantage of these technologies is that they can reduce overall disposal costs. The primary disadvantage of densification and sludge drying technologies is that they are not self-sufficient; they require energy to operate. While sludge drying/dewatering is directly applicable to septic waste, the resulting waste product has a low heating value as a fuel. Less energy intensive ways are available to dry sludge. Percolating drying beds offer a low cost, low technical method of drying sludge. These systems can be expedited by use of solar collectors and solar roofs such as those used in solar wood kilns.

Densification technologies prefer a moisture content of about 20%. If the moisture is too high, the pressure from the extruder will smash the formed briquette as it exits the extruder. If the moisture is too low, the unit will have trouble forming a mass and the resulting briquette will crumble. A dryer can be added to handle excess moisture. The average energy consumption of a small shredder/briquetter system is about 10 kW, which is easily supplied by a small gasifier. The densified products can be used in gasifiers, coal-fired boilers/furnaces, and fireplaces. The technologies are most suitable for wood and cardboard or a blend of waste that includes these constituents. These technologies range from at least $30,000 to over $100,000, depending on the throughput requirements and vendor options.

Evaluation

A qualitative evaluation of the technology groupings is presented in Table 1. A qualitative comparison is the only type of analysis possible at this stage due to the limited amount of information available and the wide range of technologies included in each grouping. Darker shading indicates a greater potential to meet the Gates Foundation criteria. No shading indicates a low potential to meet this criterion. Recognize that some technologies within a grouping may be stronger than others for meeting the criteria. Also, there is a trade-off between capacity and footprint. In summary, this comparison points to strengths and weaknesses of each technology group, but also indicates anaerobic digesters have the most potential to meet the criteria of the Gates Foundation's Omni-Processor Project. Based on this preliminary comparison, an additional search was conducted for organizations that provide anaerobic digester technologies.

Table 1. Qualitative Evaluation

Criteria **Technology Group**	**Segregate and Process Human *and* Organic Waste**	**Capacity of 0.5-5 tons per day for Service to 1-5K people**	**Create a Useful Byproduct**	**Robust for Developing Country Conditions**	**Low Cost**
Thermal Waste-to-Energy (Gasifiers)					
Composting					
Toilet Options/Sanitation*					
Material Processing					
Biological Waste-to-Energy (Anaerobic Digesters)					

* Subset of composting

Table 1 excludes the requirement of the desired footprint of less than 3-6 square meters and less than 3 meters height. The "footprint" of the Omni-Processor prototype presents challenges from a technology perspective. CTC found no one technology that could fit in the desired footprint and fulfill all the other criteria. For example, the APL GEK Power Pallet almost meets the footprint requirement, but it still needs additional equipment to process MSW. The smallest anaerobic digester was the ZWES at 45,000 liters and 40-feet long. Relative technologies with the smallest footprint are highlighted in the report and spreadsheet.

Findings from Anaerobic Digester Organizations

This section presents a summary of findings from the research into individual anaerobic digester and biogas organizations offering commercial products. This summary led to initial observations on the feasibility of adapting these for use in the Omni-Processor project. Attempts to obtain additional information on commercially available biogas systems produced very limited results due to the international nature of the industry and the time period of this project. However, the direct communication that took place was successful and provided useful insights. Additional information on the industry, the systems and the potential for technology development to meet the goals of the Gates Foundation was obtained through telephone conversations with four organizations highlighted in green in the "Down Select" tab of the spreadsheet in Attachment A.

The major differences between companies that provide anaerobic digesters are the size of the desired facility, level of involvement from the company, and the intended substrate. Many substrates can be used in anaerobic digestion (energy crop, human waste, food waste, farm waste, slaughterhouse waste); however, not all are equal for biogas production. For instance, fresh human waste is better than waste that has been in a septic tank because the waste loses its volatile content during degradation in the septic tank. Consequently, human waste that is pumped out of a septic tank should be mixed with other forms of organic waste to maximize biogas production. Water and power are required to start a biogas plant but, after this, a plant may require no outside utilities while in operation.

Currently, most biogas digestion throughput is characterized by the use of wet waste; uses of dry waste (such as fecal matter delivered from a non-flushing latrine pit) will not directly convert into the amount that a wet waste facility can handle. Most biogas digesters are "stackable," meaning that a facility can contain any number of fermentation units to accommodate nearly any amount of waste, allowing space to be the only limitation on facility size. Large plants will require at least three personnel on staff to service the plant, as full maintenance checks are required each day. Wet waste biogas plants will require fewer employees as pumps will be used to move the waste; dry waste biogas plants will require more to operate loaders and other waste moving machinery.

None of the contacted companies have applied their technology to a dense urban setting of the scale proposed by the Gates Foundation, nor have these organizations used their technology in impoverished areas. However, these ideas are not new to the representatives. The representatives were familiar with the interest in adapting the anaerobic digestion technology in these applications, but the technology has not progressed to those regions yet. Responses indicated the primary reason was return on investment; the systems are too costly based on the value of the byproducts. One representative indicated that they could build a plant with the specifications of 0.5 to 5 tons per day (1825 tons per year). The reason that no one has constructed something this small is because the upfront capital cost for a plant with a throughput of 3 to 5 tons per day would be approximately $3 to 5 million. However, electricity production would be less than 20 kW per day.

Finally, it is significant to note that the following companies expressed interest in investigating applications of their technologies in developing countries and in some cases are already moving in the direction of leveraging local waste sources to produce the needed energy to power the treatment units. For example, the search for improved applications is exemplified through the cooperative relationship identified between Swedish Biogas International and the University of Michigan to determine the feasibility of generating value-added products from commercial-scale production of biogas.[xiii]

Anaerobic Digestion Technology Vendors

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4. Recommendations

Based on the findings of this rapid technology screening, CTC recommends that the Gates Foundation focus its attention on anaerobic digester technology. This technology appears to have the most potential to meet the desired characteristics of the Omni Processor Project. The technology has been used for individual families and farms in rural areas, for orphanages, schools and hospitals, and also for large-scale industrial farming operations. In these applications, the technology performs as designed and produces biogas, fertilizer and heat. Other technology groups identified can also be adapted to meet Gates Foundation interests, but not in as many aspects as the digesters. More detailed information is needed to conduct a quantitative comparison of the technology groups.

Although requiring a larger footprint than the Foundation wants, a more complete conversion strategy would be the pairing of a small anaerobic digester, such as the ZWES anaerobic digester, and a small-scale gasifier, such as the APL GEK Power Pallet. A shredder and densification system would also likely be needed. As previously mentioned, this hybrid system could handle all waste components of an urban center with the exception of noncombustible waste such as glass and metals as well as hazardous and medical wastes. Other advantages would include a higher energy output and the ability to handle non-biodegradeable materials, such as fibers and plastics, with the gasifier. The liquid fraction would be handled by the anaerobic digester. The blending of the biogas from the digester with the hydrogen-rich producer gas from the gasifier would offer a more combustible gas for an internal combustion engine.

There are significant challenges in adapting any of the technologies identified to the scale and context of interest to the Gates Foundation. A major challenge is the need for effective methods for emptying latrines, transporting waste and then utilizing the byproducts. Without cost-effective mechanisms for removal of waste and transport to the central processing point, issues with dumping will continue. Also, in areas without power and natural gas infrastructure, the generated biogas must be used in close proximity to the plant unless technologies for cleaning and storing the gas are also deployed. Similarly, customers for the fertilizer are necessary. Cost is also a substantial challenge, as digesters of the needed scale do not currently provide enough byproducts to fully offset the costs of unit installation and operation. Further development is needed to adapt the technology for the urban, community-scale applications, and there appears to be an interest from commercial providers to conduct research and development in this area.

5. Attachment A

Gates-Foundation-spreadsheet.xls

Citations

[i] *World Watch*, Nov-Dec 1995 v8 n6 p21(3) , http://www.faculty.fairfield.edu/faculty/hodgson/Courses/so191/SouthAsReadings/IndiaEnergySuccess.html.

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