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THE CENTER FOR SUSTAINABLE UTILIZATION OF RESOURCES: QUANTIFYING CLIMATE CHANGE IMPACTS OF MANAGING WASTES

Maria Zannes (The Zannes Firm, 416 Central S.E., Albuquerque, New Mexico 87110; mariazannes@hotmail.com), Morton Barlaz (Civil and Environmental Engineering, North Carolina State University), Marco Castaldi and Nickolas J. Themelis (Earth and Environmental Engineering and Earth Engineering Center, Columbia University)

ABSTRACT

The environmental impact and potential for utilization of the billions of tons of used products and materials discarded each year by humanity is immense. The sheer magnitude of the materials and complexity of waste management and reuse make the issue of quantifying impacts and best practices all the more difficult. In recognition of this task, the Earth Engineering Center (EEC) of Columbia University and the Environmental Engineering Group of North Carolina State University combined resources in 2008 to form a research organization that is focused on defining and promoting best practices for sustainable waste management. This is the Center for Sustainable Use of Resources (SUR; wwwSURcenter.org) and its mission is to quantify the greenhouse gas emissions and other life cycle impacts of various "waste" management practices; and use this information for advancing the best practical means for managing used materials, in the U.S. and globally. The SUR Center builds on the strengths of past research at Columbia and North Carolina State on recycling, composting, waste-to-energy, and landfilling. This paper describes some of the research work completed and underway at the Center.

1.White Paper on Organics Diversion Study

In 2008, SUR researchers completed an assessment of the state-of-the-practice of food waste composting in North America. The diversion of food waste from landfills represents a large potential opportunity as it is estimated that less than 2% of food waste generated in the U.S is recovered for composting. With this opportunity comes the challenge to develop implementation strategies that can be scaled up and are economical.

Food waste is generated in the residential, and commercial, institutional and industrial (ICI) sectors. The easiest material to collect is that from large generators of reasonably pure material as is generated in the ICI sector (e.g. grocery stores, farmers markets, food processing facilities, large restaurants). In each case, training and commitment is required on the part of the waste generators to insure a feedstock that is largely free of contaminants. If a pure feedstock can be source-separated, there are multiple several proven technologies for the aerobic or anaerobic treatment of food waste. The product of each technology has the potential to be useful as a soil amendment and possibly as a fertilizer. Technology selection will be guided by project economics, the need for odor control, and location. There are many regional factors that will influence technology selection including the cost of competing waste management alternatives, local regulations, willingness on the part of the waste generators to source separate food wastes and pay a premium for a more sophisticated technology, population density and emissions standards.

Every facility visited by SUR in 2008 was able to sell all of the material generated and each facility operator indicated that there was excess demand. The benefits of compost as a soil amendment are well documented, even if they are hard to quantify from a life-cycle perspective. At the present time, the food wastes generated in the U.S. are estimated over 30 million tons but less than one million tons are composted. There is potential to increase the production of food waste compost by an order of magnitude but it is important to assess whether demand is sufficient to absorb such an increase in supply in certain regions.

There are a number of practical implementation issues that must be addressed, the most important of which are project economics and feedstock purity. Project economics will vary by region as indicated above. Feedstock purity can be obtained by enforcement of contaminant standards and/or sorting of the feedstock prior to and after composting.

Anaerobic digestion (AD) of source-separated organics is the most desirable alternative from an environmental perspective because of the generation of both methane, and, after aerobic curing, a soil amendment comparable to that generated after composting. The only large scale AD plant in North America, the Dufferin facility in Toronto, was visited by SUR (report submitted to WMI in May 2008). Although the citizens are doing a remarkable job in separating their food wastes, there is still a 10% plant residue. The SUR analysis also showed that the AD process in fact consists of two stages: Composting and curing. The Toronto AD plant sends its semi-finished compost to a windrow composting operation for curing. A second AD plant at Newcastle, Ontario, was provided with an in-vessel curing facility at the AD site. However, the curing operation resulted in undesirable odors that forced this plant to curtail operation and eventually close.

At present, the cost of anaerobic digestion is in the same range as that of mass burn combustion. R&D that can reduce the cost of AD without affecting methane production would result in wider adoption of this technology. In summary, the technologies to produce useful products from either aerobic of anaerobic treatment of source separated organics are in place. Widespread adoption will be governed by policy incentives, favorable economics, and/or regulation.

2.Life-Cycle Analysis of GHG Impacts of Composting Green Waste versus Use of Green Waste as ADC

The basic question to be answered by this project is: "From a total environmental perspective is it better to compost or use green wastes as ADC in landfills?" A preliminary report on on-going research showed that for landfills that practice reasonable landfill gas (LFG) recovery and utilization, there are no net carbon emissions associated with the use of source-separated yard wastes (SSYW) as alternate daily cover (ADC).

The use of one ton of shredded SSYW as ADC avoids the use of about six tons of soil. In all three cases examined (Table 1), the net GHG of SSYW emission is less than zero which indicates that the use of yard waste as ADC in a landfill results in a net decrease in greenhouse gas emissions. SUR considers the collection efficiencies in Case 3 to be the most realistic for a well operated landfill that is making an effort to collect and control methane emissions. As shown in Table 1, more aggressive gas collection (Cases 1 and 2) results in reduced greenhouse gas emissions.

Table 1. Results of Carbon Footprint Analysis (kg C per kg of wet yard wastes landfilled)

Case	Emissions	Sequestration	Electricity Offset	Net C
1	0.051	-0.18	-0.008	-0.137
2	0.084	-0.18	-0.006	-0.101
3	0.115	-0.18	-0.005	-0.070

3.Analysis of U.S. and Global Landfilling and LFG generation and capture

The objective of this project is to determine the present status of landfill and LFG capture technology used world-wide. Prof. Themelis presented and published in the Proceedings of the Global Waste Management Symposium (September 2008) a paper in the session Sustainable Waste Management and Climate Change, titled "Reducing Landfill Methane Emissions and Expansion of the Hierarchy of Waste Management". This paper highlighted the fact that the US is the world leader in the capture and utilization of LFG and that, globally, 80% of the landfilling is done in non-regulation landfills where there is no collection of LFG. The paper proposed that the EPA and EU hierarchy be modified so as to encourage the implementation of LFG capture and utilization, as illustrated in Figure 1 below.

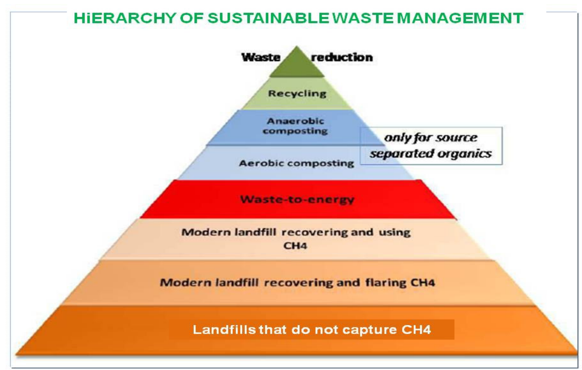

Figure 1. The expanded hierarchy of Sustainable Waste Management

A subsequent analysis of the operating1054 landfills in the EPA database showed that nearly two thirds of the MSW were landfilled with LFG recovery. The results are summarized in Figure 2..

SUR Analysis of EPA Database of operating U.S. Landfills

MSW landfilled annually *(1052 landfills)*	MSW landfilled annually in landfills that recover LFG *(376 landfills)*	LFG captured in 2006	Average LFG captured per ton MSW at landfills that recover LFG
189 million tons*	125 million tons	7800 million Nm3	62 Nm3/ton (Nm3: standard cubic meters of LFG)
100%	66%		

*vs 266 million tons landfilled as per BioCycle/Columbia survey[4]

Figure 2. Results of analysis of 1054 landfills in EPA database

The BioCycle/Columbia national survey of 2006 waste management data was published in December 2008. The results (Figure 3) showed that generation, recycling and landfilling of MSW increased since 2004 but combustion with energy recovery remained constant.

U.S. MSW generation and disposal in 2006

BioCycle/Columbia University national survey

(published in BioCycle journal, December 2008)

	MSW Generated	Recycled or composted	Waste-to-Energy	Landfilled
Generated, million U.S. tons	413	118	28	266
Percent distribution	100%	28.6%	6.9%	64.5%

Figure 3. U.S. Generation and disposition of MSW in 2006 (BioCycle/Columbia)

4.Carbon Sequestration in Landfills

Eleven statewide waste characterization studies were compared to assess variation in the quantity and composition of waste after separation of recyclable and compostable materials, i.e. discarded waste. These data were also used to assess the impact of varying composition on sequestered carbon and methane yield. Inconsistencies in the designation of waste component categories and definitions were the primary differences between study methodologies; however, sampling methodologies were consistent with recommended protocols. The average municipal solid waste (MSW) discard rate based on the statewide studies was 1.90 kg MSW $person^{-1}$ day^{-1} which was within the range of two national estimates: 2.35 and 1.46 kg MSW $person^{-1}$ day^{-1}. Dominant components in MSW discards were similar between studies. Organics (food waste, yard trimmings), paper, and plastic components averaged 23.6±4.9%, 28.5±6.5% and 10.6±3.0% of discarded MSW, respectively. Construction and demolition (C&D) waste was 20.2±9.7% of total solid waste discards (i.e., MSW plus C&D). Based on average statewide waste composition data, a carbon sequestration factor (CSF) for MSW of 0.13 kg C dry kg MSW^{-1} was calculated. For C&D waste, a CSF of 0.14 kg C dry kg C&D $waste^{-1}$ was estimated. Ultimate methane yields (Lo) of 59.1 and 63.9 m^3 CH_4 wet Mg $refuse^{-1}$ were computed using EPA and state characterization study data, respectively, and were lower than AP-42 guidelines. Recycling, combustion and other management practices at the local level could significantly impact CSF and Lo estimates which are sensitive to the relative fraction of organic components in discarded MSW and C&D waste.

5. Utilization of Landfill Gas

The purpose of this study is to investigate and compare the efficiency, economics and environmental impacts of different landfill gas to energy (LFGTE) technologies. A methane generation potential default value for an average landfill is 2.72 cf/lb, suggested by the EPA's *Turning a Liability into an Asset*,[1] and a typical range for collection efficiency according to EPA's AP-42, is 60%-85% with an average of 75%[2] and accepted average landfill gas (LFG) energy content is 500 btu/scf. A Columbia University study investigated utilizing LFG as a fuel with various energy conversion technologies and found that the highest conversion efficiency possible from the devices studied was 30%. EPA requires all but the smallest of landfills to collect and flare the LFG produced. However, many smaller landfills do not produce adequate flow rates of gas or do not have high enough energy content to justify electricity production. In those cases the LFG is flared with no energy recovery. The purpose of this study is to investigate and compare the efficiency, economics and environmental impacts of different landfill gas to energy (LFGTE) technologies. The study is not all inclusive, but one specific model from each of the following technologies is being studied:

- molten carbonate fuel cell
- phosphoric acid fuel cell
- internal combustion reciprocating engine
- gas turbine
- microturbine
- organic rankine cycle engine

[1] Turning a Liability into an Asset. Sept 1996. 2-6 http://www.epa.gov/lmop/res/pdf/hand_1.pdf

[2] Compilation of Air Pollution Emissions Factors. Fifth Edition. Jan 1995. 2.4-7

- stirling cycle engine.

This study is still in progress but Table 2 and Figure 4 show some preliminary results.

Table 2. Comparison of emissions from different energy generators

Technology	**Emissions (lb/million Btu)**									
Flares	CO	CO2	CH4	NOx	Sox	NMOC	UHC	VOC	PM10	HCs[3]
- Open- PEI	0.037	NR	0.83[2]	0.07	NR	NR	NR	NR	NR	0.83
- Enclosed- PEI	0.150	NR	0.42[2]	0.06	NR	NR	NR	NR	NR	0.42
Fuel Cells[4]										
MCFC										
-Fuelcell Energy DFC1500	NR	135	0.47[2]	0.001	0.00001	NR	NR	NR	0.000003	0.00
PAFC										
- Purecell	0.0009	119	0.00	0.004	0.00	NR	NR	0.00	0.00	0.00
ICRE										
-Caterpillar G3516 LE	0.84	227[1]	0.64	0.56	NR	0.11	NR	NR	NR	0.75
Gas Turbine										
-Solar Centaur 40 (CAT)	0.54	146	0.21[2]	0.19	0.003	NR	0.155	0.003	0.033	0.16
MicroTurbine										
-Capstone CR 200	0.35	NR	0.21[2]	0.04	NR	NR	NR	0.01	NR	0.22
ORC										
- Tri-O-Gen	0.15[5]	NR	0.42[2]	0.06[5]	NR	NR	NR	NR	NR	0.42
Stirling Cycle										
-Stirling Biopower	0.34	NR	0.42[2]	0.06	NR	NR	NR	NR	NR	0.00

"NR" stands for not rated; "0" signifies negligible or undetectable amount

[1]Caterpillar's G3516 LE was not rated for CO_2 emissions, but could be calculated based on the AFR and the mass of the exhaust.

[2]Methane emissions calculated from methane destruction efficiencies. Open flares are required to have at least a 98% methane DE. Bay Area Air Quality Management District rates enclosed flares at 99%. The California Climate Action Registry Landfill Project Reporting Protocol gives a DE of 99.5% for turbines. The stirling cycle and ORC engine were assumed to have a 99% efficiency like the enclosed flare and the DC1500 was assumed to be 99% as well.

[3]HC emissions were derived from the rated CH4, NMOC, UHC, and/or VOCs

[4]Note that the contaminants from the waste stream of the CO_2 Wash technology are flared, but the emissions from this process are not recorded here.

[5]The values are the same as the flare values because the ORC engine is run off flare exhaust heat.

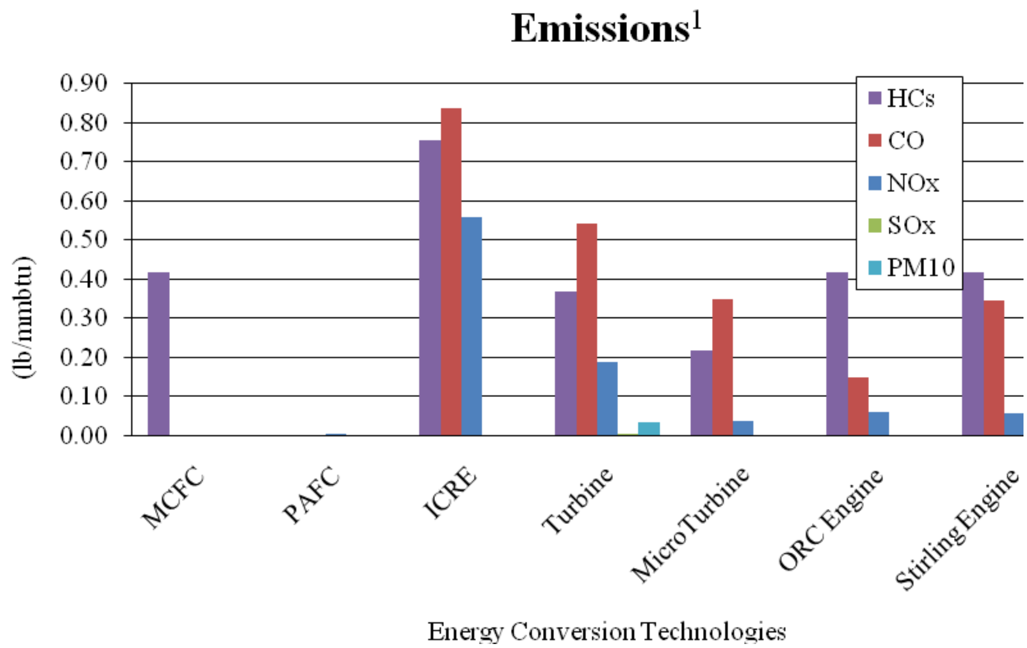

Figure 4. Emission comparison for various LFGTE technologies

REFERENCES

For more information on these and other ongoing projects of the Center for Sustainable Use of Resources, please refer to www.SURCenter.org