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FEASIBILITY STUDY OF WASTE TO ENERGY CONVERSION FROM MUNICIPAL SOLID WASTE IN CHARLOTTE-MECKLENBURG COUNTY, NORTH CAROLINA

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ABSTRACT

In this paper Charlotte-Mecklenburg County waste generation data has been used to study the feasibility of recovering energy from municipal solid waste (MSW) generation. To do so, the study evaluated greenhouse gas emissions of the waste material based on a life cycle assessment approach developed by the United States Environmental Protection Agency. The study focuses on energy recovery potential and economic analysis of Charlotte-Mecklenburg county MSW. The waste-to-energy assessment considered the short-term and long-term plans of the County's MSW practices in determining the cost of incineration. Assumptions are adopted from World Bank guideline for an incineration plant. The literature review has been done on European best practices with MSW to determine a more management oriented strategy to handle waste. Methodology included waste component analysis, heating value measurement, greenhouse gas emission estimate, waste management plan as well as environemental impact. An average lower calorific value (LCV) of 20.34 MJ/kg was estimated from the MSW after implementing the solid waste management plan of the County, an indication of energy recovery potential. For a long-term plan with an LCV of 20.34 MJ/kg, approximately 1.8 million houses can be supplied electricity for an hour. Value of energy sale 20.34 MJ/kg of waste is $91/ton and for 16.62 MJ/kg of waste is $75/ton. If NRP is used as combustion fuel along with other fuels, we could approximately save $10,000,000 of fuel.

However, implementation of a waste incineration plant to recover energy from the commercial sector waste generated would require a per capita fee increment to $41 annually. Also waste incineration cost per kg MSW is almost $3. Finally energy potential from the current trend of waste generated has been discussed in the result section.

Keywords: *Waste generation, Energy recovery, Municipal solid waste, Greenhouse gas emission.*

1. INTRODUCTION

The Charlotte-Mecklenburg County is one of the rapidly growing urban cities in the United States since the economic downturn in 2008. The growth in population and economic activities affects systems such as transportation, solid waste management, water and wastewater, and energy which characterize urban ecosystems. Hence, there is the need to ensure these systems are economically and environmentally sustained in providing the necessary support to the urban ecosystem. Solid waste management, being intrinsic to urbanization, forms part of various systems the Charlotte-Mecklenburg County is addressing to ensure its sustainability whiles reducing its impacts on the environment and climate change.

Adopting the United States Environmental Protection Agency (EPA) waste management hierarchy, the Charlotte-Mecklenburg County, through its ten-year solid waste management plan (SWMP) developed in 1997, has embarked on sustainable solid waste management system (HDR, 2012). The plan emphasizes on, in the order of, source reduction and reuse, recycling and composting, energy recovery and disposal. The County's SWMP has since seen updates over the years with the recent one being for the period 2012-2022. Through outreach campaigns to residential and commercial sectors, significant achievement has been attained in source reduction, recycling, composting with national recognition (HDR, 2012). Nonetheless, a large amount of solid waste is disposed of in landfills. The County currently has two main landfill sites serving its waste management system. The Foxhole landfill located within the county serves construction and demolition (C&D) waste and the Speedway landfill located in the Cabarrus County. Although the Foxhole landfill has the capacity for residential and commercial waste, the contract with Cabarrus County maintains Foxhole landfill for C&D waste.

Waste incineration programs initiated by the County were abandoned simply due to the increasing cost of compliance with environmental regulations as well as Federal laws that restricted diversion of waste to the energy recovery facilities (Gledhill, 2007). However, through the advancement of technology, recovering energy from the incineration of MSW makes it a cost effective method and more sustainable method of waste management. Regarding emissions, several studies in Europe evaluating greenhouse gas (GHG) emissions from MSW incineration indicate that incineration has sinks in GHG emissions (Yang *et al.*, 2012). However, in McPhail *et al.* (2014) study on the impact of MSW composition and moisture content on the environment, cost and energy generation from co-combustion, it was concluded that further analysis is carried out on the reaction kinematics and plant operation conditions to evaluate GHG emission sinks related combustion. With best available technologies (BAT) to control emissions, MSW can provide a sustainable source of energy to compliment other sources of renewable energy in the County. Waste-to-Energy (WtE) systems derive energy in the form of heat, electricity or transport fuels from waste materials. These systems can be classified into three namely: thermo-chemical, bio-chemical and chemical conversions (World Energy Council, 2013). Smith *et al.* (2015) discusses WtE technologies as an industrial ecological approach to municipal solid waste management. Bajpai (2015) also discusses operating conditions for new technologies for extracting energy from waste such as pyrolysis, direct liquefaction among others.

Thermo-chemical conversion utilizes thermal treatment at high temperatures to extract the energy content of waste. Based on the fuel choice processes such as incineration, co-combustion, residual fuel (RDF) plant and thermal gasification can be selected (World Energy Council, 2013). Bio-chemical conversion utilizes bio-chemical processes such as fermentation, anaerobic digestion and microbial fuel cell to extract the energy content of the primary source primarily through bio-decomposition of the waste (World Energy Council, 2013). Chemical conversion – esterification is the notable chemical process that can produce varying types of biofuel from waste (World Energy Council, 2013). McPhail et al. (2014) evaluated the environmental, economic and energy impact of MSW composition and moisture content in a co-combustion system.

With the rapid increase in raw materials and energy prices in the early seventies, Majority of European countries went through a thorough review of methods for better conservation of resources and potentials of recovery and reuse of materials that have been refused as waste. To obtain a much cleaner society there was constant increase of pressure on the orthodox disposal route, landfilling etc. Those were also transforming to be more expensive due both to the reduction in available land area locatable to the centers of population. Also, the environmental issues associated with landfill e.g. leachate, methane, odor etc. (Barton, 1985). BMW is a biodegradable municipal waste. Separate BMW collection system provided by the local authorities leading to separate, mandatory BMW treatment systems in Austria and Netherlands. Some EU members use economic instrumentation like Pay-As-You-Throw (PAYT), Organic waste Tax. Example: Belgium, Norway, Ireland, Luxembourg etc. Pires et al., 2011).

In UK BMW system and Landfill Allowance Trading System (LATS) were launched to provide local authorities more flexibility to manage waste stream. LATS allows waste diversion to the cheapest and most practicable area using transferable allowances. Pires et al., 2011).

Packaging waste system promoted analogous incentives to ensure maximum reuse and recycling. The utmost popular system is Green Dot System firstly applied in Germany in 1990s and later all over Europe. The elementary idea is to establish a privately organized channel which will assure all primary packaging can be collected from the consumers goes to a material specific recycling process. The so called green dot is used to classify the product belonging to the dual system during consumption phase. (Pires et al., 2011).

Pretreatment such as sorting and homogenizing is required in implementing the incineration plan. The key waste product stream from incineration is the slag or bottom ash. Typically it amounts to 20 to 25 % by weight of the waste combusted but only to 5 to 10 percent by volume. After being removed by gravitational pull the main disposal method for slag is the landfilling. (Rand et al., 2000).

2. METHODOLOGY

2.1 Waste Composition Analysis

Data for the waste composition analysis was extracted from the waste composition study conducted by SCS Engineers for the Charlotte-Mecklenburg County in 2011. SCS ENGINEERS (2011) reported the study area for three institutions namely: Charlotte – Mecklenburg Schools (CMS), County government buildings such as the Department of Social Services and Medical Facilities (County Facilities) and the Central Piedmont Community College (CPCC) with a sample size of 50. Based on the limitation data on the County's waste composition, this study assumes that the composition analysis result generated by (SCS ENGINEERS, 2011) is a representation of the waste generated by the commercial sector for the fiscal year 2010/2011. Hence, a simple arithmetic mean of the waste composition for the three institutions mentioned above should represent the commercial sector waste generated for the fiscal year 2010/2011.

2.2 Greenhouse Gas Emission Analysis

MSW is associated with GHG emissions throughout the lifecycle of the materials which impact the environment and climate change. In assessing the GHG emissions from the solid waste management practices, the waste reduction model (WARM) developed by the United States EPA which is a life cycle assessment tool that assist solid waste mangers to report on GHG emissions reductions based on implemented waste management practices (USEPA, 2016a). For baseline and alternative waste management practices – source reduction, recycling, composting, combustion and landfilling, WARM estimates the associated GHG emissions based on emission factors developed from the life cycle of the materials. The alternative waste management practices were based on the SWMP 2012-2011 of the Charlotte-Mecklenburg County.

Although WARM accounts for emissions from incineration, this study takes into account climate-relevant emissions namely carbon dioxide (CO_2), nitrous oxide (N_2O), carbon monoxide (CO), nitrogen oxides (NO_x), ammonia NH_3), non-methane volatile organic compounds (NMVOCs) based on the proposed methodology by Lee *et al.* (2001) as follows:

2.3 Waste Management Plan

2.3.1 Charlotte-Mecklenburg County SWMP (Livingstone)

The County's SWMP plan had the fiscal year 1998/1999 as its baseline but for the purpose of this study and the data available, the fiscal year 2010/2011 was selected as the baseline. The revised SWMP goals for the commercial sector is shown in
Table *1* below.

Table 1. Revised commercial sector goals for Charlotte-Mecklenburg County for 2012-2022.

	Baseline FY10/11	**Short-Term Plan FY16/17**	**Long-Term Plan FY21/22**
Population	923,944	1,027,829	1,114,398
Disposal tons if NO new programs	513,081	637,665	691,373
Disposal tons with PROPOSED short-term programs	N/A	575,376	623,837
Disposal tons with PROPOSED short-term and long-term programs	N/A	N/A	512,888
Proposed rate tons/person/year	0.56	0.56	0.46
Rate reduction % of baseline year	N/A	0%	18%
Proposed tons diverted from disposal	N/A	62,289	178,485

2.4 Heating Value Analysis

The capability of municipal solid waste to sustain a combustion process without auxiliary fuel depends on a few physio-chemical parameters, of which the lower calorific value (LCV) is the most vital. Besides it also depends on the water content of the municipal solid waste. The higher the moisture content the more fuel is required to burn the waste. A wet waste with a moisture content greater than 95% percent or a sludge waste with less than 15% percent solids content would be considered poor for incineration (Brunner, 1991). Water vapors from the combustion process and the moisture content of the fuel disperse with the flue gasses during ignition. The energy content of the water vapors is actually the difference between a fuel's higher calorific value (HCV) and lower calorific value (LCV). If the LCV is not noteworthy, incineration would not be a feasible disposal method. Usually a waste with a heating value less than 1000 BTU/lb is not relevant for ignition.(Brunner, 1991) MSW with a soul purpose of combustion should have a LCV of minimum level. The requirement of minimum LCV for a controlled ignition also depends on the incinerator design. If MSW is burnt with assistance of low-grade fuels, it must need a heat loss minimization strategy with a drying of waste before ignition. (Rand *et al.*, 2000).

2.5 Heating Value Measurement:

The most reliable method of determining heating value quantities is by experiment. The most widely used equipment for testing for heating value is the oxygen bomb calorimeter. In this apparatus a measured sample typically 1 g, is ignited in an atmosphere of pure oxygen by an electric wire. When the sample heat of combustion heats a water bath surrounding the bomb the water bath temperature rises and the heat of combustion is calculated from this temperature increase (Brunner, 1991).

2.5.1 *Assessment of Heating Values of Mecklenburg MSW:*

After carefully performing literature review, we have chosen the Modified Dulong model for estimating the heating value of MSW. There are also other models like Modified shafizadeh model. The LCV differs from the HCV by the heat of condensation of the combined water vapors, which comes from the fuel's moisture content and the hydrogen released through combustion (Rand *et al.*, 2000).

Modified Dulong model:

$$HCV\ \left(kJ/kg\right) = 337C + 1428\left(H - O/8\right) + 95S \tag{1}$$

$$LCV\left(kJ/kg\right) = HCV - 0.212H - 0.0245W - 0.008O \tag{2}$$

Where, C: Carbon%; H: Hydrogen %; O: Oxygen %; S: Sulfur %; and W: water content % (Menikpura *et al.*, 2007).

2.6 Chemical Composition of MSW

There are two types of chemical composition analysis namely:
Proximate analysis - It is a comparatively swift and economical laboratory test to determine the percentages of moisture, volatile matter, fixed carbon and ash.
Ultimate analysis - It is a standard approach to determine the quantities of fundamental components present in a sample. It is an obligatory process to determine the products of combustion of a material, its combustion air requisite and the nature of the combustion products. Carbon, Hydrogen, Sulfur, Oxygen, Nitrogen, Halogens, Heavy Metals can be determined from this analysis. (Brunner, 1991). As we did not have any scope to do laboratory test in this class project, we have used literature review to best fit the chemical composition of Mecklenburg county waste.

In performing the chemical composition analysis the study relied on literature review (Shi *et al.*, 2016) in the absence of laboratory test, we used the effort exerted by (Shi *et al.*, 2016) in tabulating different chemical composition of MSW around the world. In the attached excel sheet the County's waste was compared to 153 type of waste category to determine the chemical composition. And further validated using the F test, a statistical analysis tool. For example we had to make assumptions like similarity in types and characteristics of plastics or paper wastes from the literature review. We have also made assumptions from the book 'Integrated Solid Waste Management' (Tchobanoglous *et al.*, 1993) on water content of different waste component.

2.7 Cost Estimation of Mecklenburg MSW

Assumptions are as follows:

- The average LCV of the waste must be at least 6 MJ/kg throughout all seasons. The yearly average lower calorific value must not be less than 7 MJ/kg.
- Plant life span assumed to be 15 years.
- According to the World Bank guideline, the annual amount of waste for incineration should not be less than 50,000 metric tons and the weekly variations in the waste supply to the plant should not exceed 20 percent (Rand *et al.*, 2000).
- A LCV of the waste of 20.34 MJ/kg and 16.62 MJ/kg (Please refer to Results section) is assumed as the design basis. A higher calorific value will increase the actual investment costs and vice versa.
- For compliance with basic level emission control the total investment cost can be reduced 10%. But for an advanced level control it will go high 15% of total investment cost.

- The operating and maintenance costs comprise of fixed (i.e. administrative cost or salary) and variable operating costs (gas cleaning system, electricity bill, water bill, waste water handling cost, residual disposal etc.)
- Maintenance costs comprises of machine maintenance, building maintenance etc.
- Capital cost has a 6% interest rate.
- The income from sale of energy is based on the lower calorific value (LCV) of the waste of 20.34 MJ/kg.

2.8 Flue Gas Volume Calculation

$$\textit{Flue gas volume} = 2 \times LCV \times (273 + t) / (21 - y)(100 - z) \tag{3}$$

Where LCV = low heating value;
t = temperature of combustion;
y = oxygen content; and
z = water vapor content of MSW
For MSW incineration, the standard condition is most often 0 °C (= 273 K), 101.3 kPa (= ~ 1 Atm.), 0 % H2O, 11% O_2. This is the standard condition. Volumes corrected to 0 °C and 101.3 kPa are named Standard or Normal cubic meters = Nm^3. (Rand *et al.*, 2000)

2.9 Environmental Impacts

3. RESULT & DISCUSSIONS

Based on the assumptions made in this study and for the baseline 2010/2011, the commercial waste composition is summarized as shown in

Figure *1* below. Review of the detailed waste composition result by SCS ENGINEERS (2011) indicated some marginal errors as some exhibitions did not add up to 100 % whiles others exceeded 100 % marginally. However, the study adjusted values less than 0.01% where necessary to zero resulting in an increase in commercial waste generated for FY 2010/2011 from 513,081 tons to 526,421 tons.

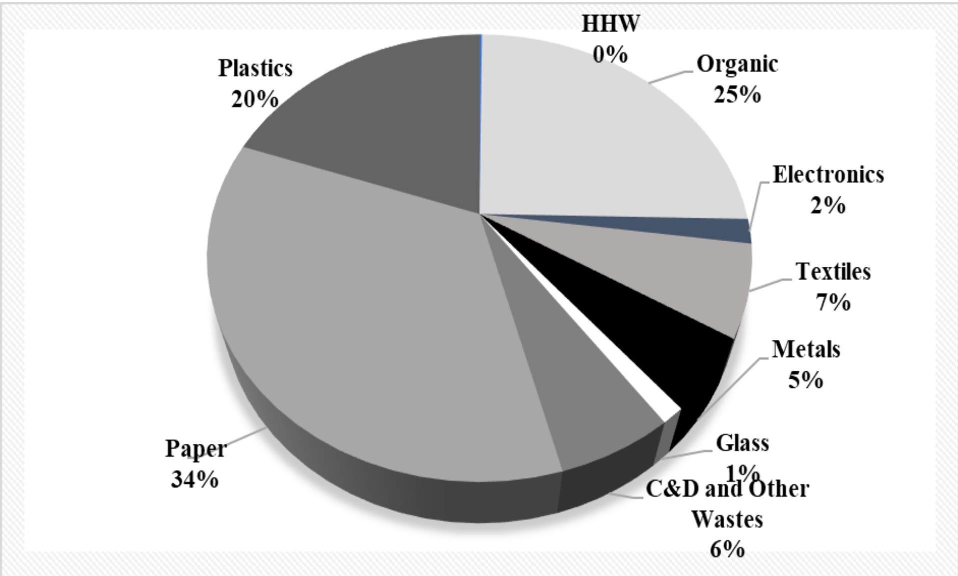

Figure 1: Assumed commercial waste composition.

Two scenarios were assessed using WARM to evaluate the GHG emissions based on the life cycle of the waste material. The first scenario considers the County's SWMP of source reduction and recycling whereas the second scenario included incineration (combustion) in addition to the above mentioned plans. Results are shown in
Figure *2* below.

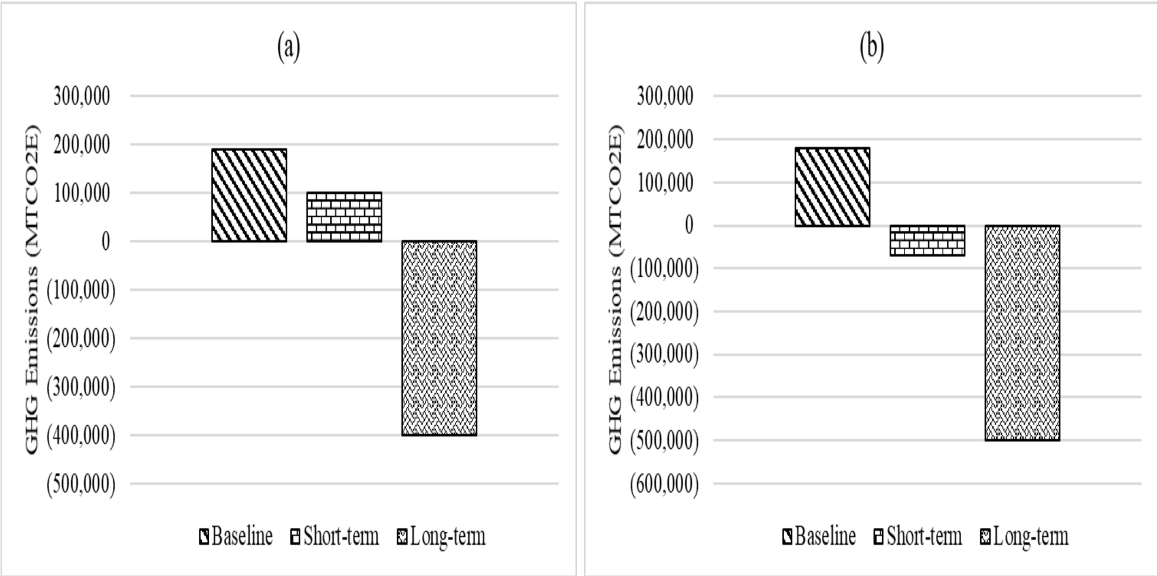

Figure 2: GHG emission results (a) without combustion (b) with combustion

For
Figure *2* (a), the short-term goal which excludes source reduction, diverted approximately 10% of waste generated to recycling and composting facilities resulting in a 45% reduction in GHG emissions compared to the baseline. Significant savings in GHG emissions of about 300% was made in the long term goal which seeks to achieve 18% source reduction, and 26 % recycling and composting. Recycling displaces 100 % virgin inputs whereas source reduction displaces some recycled and some virgin inputs. These account for the significant saving made in the GHG emissions considering the County's SWMP. The incorporation of combustion resulted in significant savings as shown in
Figure *2* (b). GHG emissions from biogenic materials are considered savings, hence, the presence of more biogenic material than non-biogenic material in combusted wasted results in some amount of savings which was the case in the results in
Figure *2* (b).

From equation (1) and (2) the average LCV was estimated to be 20.36 MJ/Kg considering the County's SWMP. Assuming a 100% recycling, the LCV = 16.62 MJ/kg. LCV value of 34.18 MJ/Kg was estimated for only non-recyclable plastic in the waste generated to compare the MSW as a partial replacement of fuel to burn MSW. From cost estimation the total costing of MSW incineration per kg for both long and short term is almost the same:

Table 2. Incineration cost per kg.

LCV(BTU/kg)	LCV (MJ/kg)	Total Cost (USD/kg)
19,279	20.34	$ 2.10
15,753	16.62	$ 1.05

But as the reduction scheme is not possible to implement in short term strategy taken by Mecklenburg County the per capita cost for incineration goes higher in case of short term. As incineration is not implementable within this short period, the only representable per capita cost for incineration is:

Table 3. Annual per capita cost for incineration

LCV(BTU/kg)	**LCV (MJ/kg)**	**$/per capita/annually**
19,279	20.34	$ 491.93
15,753	16.62	$ 240.46

Energy potential of 20.34 MJ/kg waste is equivalent to 4.56 MWh/m ton and 16.62 MJ/kg is equivalent to 3.74 MWh/m ton. For a long-term plan with an LCV of 20.34 MJ/kg, approximately 1.8 million houses can be supplied electricity for an hour. Value of energy sale 20.34 MJ/kg of waste is $91/ton and for 16.62 MJ/kg of waste is $75/ton. If NRP is used as combustion fuel along with other fuels, we could approximately save $10,000,000 of fuel.

4. CONCLUSIONS

- MSW should be considered as a supplemental source of energy for some facilities e.g. cement factories and brick production plants as these plants rely heavily on fossil fuel to generate heat for their production.
- Incineration of msw to recover energy under bat can be considered in the north carolina state’s renewable energy sources whiles saving on the capacity of available landfills.
- Co-combustion (natural gas) should be considered to increase the heating value of the MSW as well as improve the emission quality.
- Using nrps as fuel can save fuel cost up to $10,000,000 annually.
- Biodegradable waste separation can be considered as an option for bio-chemical conversion e.g. austria and netherlands.
- PAY-AS-YOU-THROW (PAYT) OR BMW taxation should be implemented as a scheme to reduce waste generation. if waste is significantly reduced tax rebate can be declared to honor each household.
- Further studies should be performed to determine the optimum amount of waste to be reduced, recycled, composted and incinerated in order to make the swmp a cost effective one. As these alternatives have some benefits to offer the system in making it sustainable.

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