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Converting campus waste into renewable energy – A case study for the University of Cincinnati

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ABSTRACT

This paper evaluates the implementation of three waste-to-energy projects at the University of Cincinnati: waste cooking oil-to-biodiesel, waste paper-to-fuel pellets and food waste-to-biogas, respectively. The implementation of these waste-to-energy (WTE) projects would lead to the improvement of campus sustainability by minimizing waste management efforts and reducing GHG emissions via the displacement of fossil fuel usage. Technical and economic aspects of their implementation were assessed and the corresponding GHG reduction was estimated. Results showed that on-site implementation of these projects would: (1) divert 3682 L (974 gallons) of waste cooking oil to 3712 L (982 gallons) of biodiesel; (2) produce 138 tonnes of fuel pellets from 133 tonnes of waste paper (with the addition of 20.75 tonnes of plastics) to replace121 tonnes of coal; and (3) produce biogas that would be enough to replace 12,767 m^3 natural gas every year from 146 tonnes of food waste. The economic analysis determined that the payback periods for the three projects would be 16 months for the biodiesel, 155 months for the fuel pellet, and 74 months for the biogas projects. The reduction of GHG emission from the implementation of the three WTE projects was determined to be 9.37 (biodiesel), 260.49 (fuel pellets), and 11.36 (biogas) tonnes of CO_2-eq per year, respectively.

1. Introduction

Universities are the place where knowledge is taught, ideas are inspired and technologies are developed. These activities lead to the consumption of resources, including energy, water, and food, which in turn result in the generation of waste (Alshuwaikhat and Abubakar, 2008; Smyth et al., 2010). A mission of many universities in the US is to promote the idea of sustainability among students, faculty, and the society (Cortese, 2003). Therefore, improving resource management and minimizing waste generation are two key challenges for universities to address in achieving those campus sustainability goals. One solution is to recycle wastes and reuse them on-site for energy production. Converting waste into energy minimizes campus wide waste disposal efforts while at the same time providing the university with energy that reduces GHG emissions from replacing fossil fuels. The on-site implementation of the proposed waste-to-energy options has an additional advantage of eliminating the transportation required for ultimate disposal, which further reduces fuel consumption and associated GHG emissions.

This paper evaluates the implementation of three WTE pathways, namely, waste cooking oil-to-biodiesel, waste paper-to-fuel pellets and food waste-to-biogas at the University of Cincinnati. The selection of these three WTE pathways was based on the goal of leveraging existing infrastructure as well as fitting the best interest for the University of Cincinnati. For example, making waste cooking oil into biodiesel leverages the existing biodiesel production system at UC. The food waste-to-biogas pathway was selected because a reduction in GHG emissions was expected to be higher than composting (Zhu, 2014). In addition, there is an ongoing algae-to-biofuel pilot project that can potentially use the CO_2 in the biogas as carbon source for algae growth. The paper-to-fuel pellets pathway was selected because of its relatively simple manufacturing process and more importantly due to the need to replace coal at one of UC's utility plant. Biodiesel is a mixture of fatty acid methyl esters (FAME) that are derived from renewable feedstocks such as vegetable oils, animal fats, and waste oil and greases via transesterification (Clements and van Gerpen, 2004; Chai et al., 2014). Biodiesel displays comparable fuel properties with petrochemical diesel fuel, while significantly reducing the emission of most air pollutants and greenhouse gases (GHGs). In

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addition, the production of biodiesel helps to reduce the nation's reliance on petroleum imports, which contributes to energy security proposed by the Energy Independence and Security Act (Sissine, 2007). Also, since minimal modifications on combustion system are needed for current diesel engines to run on biodiesel, biodiesel is considered as a turn-key solution to achieving a sustainable fuel supply.

Fuel pellets are a type of renewable fuel made from densified biomass, such as wood chips, saw dusts and waste papers (Mani et al., 2006; Uasuf and Becker, 2011). Fuel pellets can be used for industrial and residential electricity and heat generation. Displacing coal with fuel pellets reduces the emission of SO_x, NO_x and GHGs (Robinson et al., 2003). The market of fuel pellets has grown in recent years in the US (Pirraglia et al., 2010).

The anaerobic digestion (AD) process degrades organic matter in the absence of oxygen and generates biogas, which typically has a volumetric composition of 65% methane (CH_4) and 35% of CO_2 (Møller et al., 2009). The methane can be burned in a boiler for energy generation. A by-product called digestate can be aerobically composted and applied to agriculture land as a soil amendment (US EPA, 2011). The AD technology has been widely applied in wastewater treatment plants (WWTP) and farms for manure treatments (Moriarty, 2013). There are two types of anaerobic digesters used for solid waste: wet and dry digesters. The wet system usually deals with a low solids content (3–10%) while the dry system often handles a solids content of 15% or more. Although referred as "dry", the food waste feedstock for dry digesters generally has a moisture content over 70 (Moriarty, 2013). Food waste is a suitable feedstock for anaerobic digestion due to its high organic content and moisture level.

The University of Cincinnati has 5 campuses and this study focused on the Uptown Campus (0.55 km^2) where over 30,000 students spend most their school time. This study developed an inventory of the above mentioned three waste streams and assessed the implementation of the corresponding waste-to-energy technologies: (1) waste cooking oil to biodiesel, (2) waste paper to fuel pellets, and (3) food waste to biogas. An evaluation of their technical feasibility, economic feasibility and GHG reduction was also performed.

2. Methodology

2.1. Technical analysis

The technical feasibility of the waste-to-energy technologies was evaluated by: (1) reviewing the process type (e.g., reactor type, production scale), (2) reviewing the process requirements (e.g., feedstock, material and energy inputs), (3) reviewing existing examples at other universities, and (4) performing a material and energy on each process. Detailed calculations for the technical analysis can be found in Section S1 in the supplementary material.

2.2. Economic analysis

An economic feasibility assessment was also conducted by determining: (1) the capital investment and operational costs, (2) the savings on utility bills by replacing fossil energy with waste-to-energy, and (3) the payback periods.

The Payback period was calculated by the following equation.

$$P = A + B/C \quad (1)$$

where
P = payback period (yr).
A = the last period with a negative cumulative cash flow (yr).
B = the absolute value of cumulative cash flow at the end of the period A ($).
C = the net cash flow during the period after A ($).

The capital cost for equipment was calculated by:

$$C_c = e(C_e + C_i) \quad (2)$$

where
C_c = capital cost ($/yr).
e = capital recovery factor.
C_e = cost of the equipment ($).
C_i = installation cost for the equipment ($).

The installation cost (C_i) for the equipment can range from 40% to 75% of its capital cost. The capital recovery factor was calculated by:

$$e = \frac{i(1+i)^N}{i(1+i)^N - 1} \quad (3)$$

where
i = 6% interest rate (Mani et al., 2006).
N = lifetime of the equipment (yr).

An interest rate of 6% was chosen from an economic study of making fuel pellets from biomass (Mani et al., 2006). The scaling of equipment costs was determined by the following equation.

$$C_{eq1} = C_{eq2}\left(\frac{C_1}{C_2}\right)^g \quad (4)$$

where
C_{eq1} = cost of the equipment with desired capacity ($).
C_{eq2} = cost of the equipment with reference capacity ($).
C_1 = desired capacity of the equipment.
C_2 = reference capacity of the equipment.
g = 0.7 (Pirraglia et al., 2010).

A sensitivity analysis was performed on the payback period of the waste-to-energy projects by incorporating uncertainties associated with capital investment and operational costs. A deviation of ±30% from the baseline calculation was applied. An example of calculating payback period can be found in Section S2 in the supplementary material.

2.3. GHG emission analysis

The GHG emission analysis for the waste-to-energy options was performed from a life cycle perspective. The GHG emissions were quantified in the unit of CO_2-equivalent (CO_2-eq). The system boundary included a material and utility production stage, waste-to-energy conversion stage, and renewable energy use stage (Fig. 1). The GHG emissions for the material and energy inputs

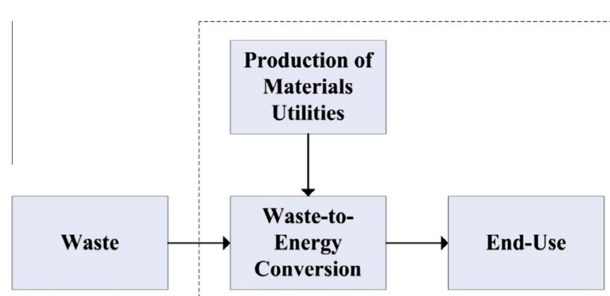

Fig. 1. System boundary for GHG emission calculations.