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Wet waste-to-energy resources in the United States

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ABSTRACT

Waste-to-energy (WTE) technologies present an opportunity to recycle organic waste material into renewable energy while offsetting disposal and environmental costs. A key challenge to ensuring economic and environmental viability of WTE is understanding the variability of individual WTE resource characteristics, including their location, amount, and quality. The main objective of this study is to estimate the wet WTE resource potential in the United States and illustrate its geographic distribution. The wet resources considered in this study are wastewater sludge, animal manure, food waste, and FOG (fats, oils, and greases). This study is the first to achieve results below national level, at the finest geographic resolution. Our analysis indicates that about 566 teragrams (Tg) of wet WTE resources are generated annually in the United States. This amount corresponds to about 1 exajoule (EJ), which is sufficient to displace about 18% of the 2015 U.S. on-highway diesel consumption on an energy basis. About half of this potential is generated by animal manure.

1. Introduction

Focus on diverting organic waste from landfills has grown significantly in recent years, resulting in efforts towards reducing and recycling (mainly composting) of these materials. Another pathway for organic waste recycling is energy recovery via various waste-to-energy (WTE) technologies such as anaerobic digestion, combustion, gasification, pyrolysis, and hydrothermal liquefaction. There are a number of waste streams to consider, including municipal solid waste (MSW), wastewater sludge, and various industrial byproducts. A key challenge to ensuring economic and environmental viability of WTE is understanding the variability of individual WTE resource characteristics, including their location, amount, and quality. This understanding can then lead to estimates of energy (including biofuels) and bioproducts potential as well as associated demand for and availability of other essential resources such as water, land, and critical infrastructure.

The main objective of this study is to estimate the wet WTE resource potential in the United States and illustrate its geographic distribution. The wet resources considered in this study are wastewater sludge, animal manure, food waste, and fats, oils, and greases (FOG). These wastes provide a landscape of carbon resources for energy production that otherwise represent mounting challenges associated with GHG emissions and ecological impacts. By providing detailed information about these resources we enable industry developers to conduct strategic logistics, infrastructure access, and other necessary analyses to accurately assess the scale and viability of WTE potential. This information is also useful for decision makers in their efforts to reduce the considerable stockpile of underutilized organic waste that has accumulated and continues to grow across the nation.

The study provides an overview of wet WTE resources, analysis methodology and data sources, estimates of the wet WTE resource potential in a graphical format (maps), comparison to other relevant studies, and assessment of current uses. In addition, we also provide a summary of all resources by state to allow comparison and support decisions about viable resource-technology pairings.

2. Overview of wet waste-to-energy resources

2.1. Wastewater sludge

Wastewater sludge refers to material "generated during the treatment of domestic sewage in a treatment works" (EPA, 1999). During wastewater treatment, debris and grit are removed from the influent wastewater before entering primary treatment where suspended solids settle out as raw primary sludge. During secondary treatment of the residual wastewater, microbes digest any remaining suspended organic matter resulting in secondary sludge, which may be wasted (removed) or returned to the treatment process. Advanced (tertiary) wastewater treatment processes may be applied to remove nutrients (e.g., nitrogen and phosphorus) or disinfect effluent prior to discharge or reuse. Many options exist for treating and handling sludge once it has been collected (Oleszkiewicz and Mavinic, 2001).

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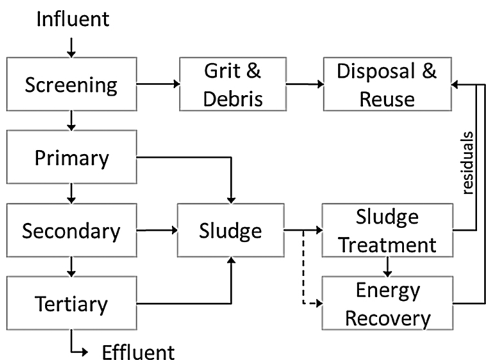

Fig. 1. Basic wastewater treatment process.

Sludge can be converted into energy by capturing methane during sludge treatment. But the conventional practice of aerobic wastewater treatment and anaerobic sludge digestion only captures a portion of potential energy and produces biogas with a negative net energy value (McCarty et al., 2011). Thermal conversion technologies, such as hydrothermal liquefaction, may allow for the direct conversion of wet municipal sludge to bio-crude, potentially reducing or eliminating the need for sludge treatment (Elliott et al., 2015). Fig. 1 summarizes the basic wastewater and sludge treatment and handling process.

2.2. Manure from confined livestock

Animal manure is organic material containing nitrogen, phosphorus, potassium, and other nutrients. This study is focused on the following animal types, as defined by the U.S. Department of Agriculture (USDA):

Feedlot beef, also known as fattened cattle, are steers and heifers being fed for slaughter. It excludes cattle being "backgrounded only" for later sale as feeders or later placement in another feedlot.

Dairy cows, also known as milk cows, are female cattle that have calved and are bred specifically for high milk production.

Market swine are non-breeding hogs intended for slaughter.

Confined poultry was not considered in this study due to (1) difficulty obtaining site-specific spatial and inventory data for poultry operations in the United States; (2) high bedding content in poultry litter (30% for broilers), which increases ash content (Bolan et al., 2010) and decreases moisture content from 74% as-excreted to 31% as-removed (ASAE, 2005); and (3) high current utilization (90%) of poultry manure as a fertilizer (Moore et al., 1995). Manure from laying-hen operations contains more liquid than broiler waste and could be considered as a wet feedstock in the future.

Livestock inventory levels have not changed substantially over the past 20 years except for poultry, which is now the most-consumed meat product in the United States (USDA, 2016a). As compared to 1997 (2002 for cattle on feed that was not reported in 1997), the 2012 USDA Census of Agriculture reported that there were 14.4 million cattle on feed (-3%), 9.3 million dairy cows (+2%), 66 million swine (+8%), and 1.97 billion chickens (+29%) (USDA 1999a, 2004, 2014).

While inventory has remained relatively steady for cattle and swine, there have been dramatic geographic shifts in all livestock production as the industry has become more concentrated and specialized (MacDonald and McBride, 2009). At the same time, improved breeding techniques and, to some extent, diet and animal management practices have substantially increased animal performance (e.g., weight gain and milk and egg yield), which also affects manure production (Chen et al., 2002; Garrick, 2011; Havenstein et al., 2003; Oltenacu and Broom, 2010).

The majority of managed manure is generated by large confined animal feeding operations (CAFO) with insufficient cropland to apply manure at agronomic rates. Approximately 68%, 16%, and 22% of total fattened cattle, dairy, and market swine production, respectively, occurs on farms with no crop acreage (MacDonald et al., 2009). Therefore, some excess manure must be transported to other farms for land application. However, high manure transport costs, a preference for commercial fertilizers, severe cropland shortages in regions with high animal concentrations, and low willingness to accept manure have resulted in excess manure application in some areas (MacDonald and 2009; Ribaudo et al., 2003; Risse et al., 2006). Manure from confined operations is generally stored in lagoons or outdoor stockpiles to decompose prior to land application (Cuéllar and Webber, 2008). Concentrating manure waste poses environmental risks to surface water, groundwater, and air quality (Bolan et al., 2010; EPA, 2004, 2013, 2016b; NALBOH, 2010; Ribaudo et al., 2003), but creates opportunities to readily collect manure for energy recovery.

2.3. Food waste

Food loss and food waste occur throughout the entire supply chain – from production, through processing, to consumption. The Food and Agriculture Organization of the United Nations (FAO) defines food loss as food that is spilled or spoiled before it reaches its final product or retail stage – for example, due to problems in harvesting, storage, packing, or transport (FAO, 2016). Food waste refers to food that is fit for human consumption but is not consumed because it is left to spoil or is discarded by retailers or consumers (FAO, 2016). Food waste, the subject of this study, comes primarily from the following four sources:

Industrial food waste includes off-spec or unsellable food and by-products (e.g. peels, trimmings, bones) at the food-processing stage, e.g., fruit and vegetable canneries, fresh/frozen fruit and vegetable processors, creameries, wineries, meat packing and processing plants, breweries and distilleries, bakeries, grain mills, soft drink bottling plants, etc.

Commercial food waste includes expired or unconsumed food at the point of sale, e.g., supermarkets or restaurants. Food waste from airports is also considered under this category.

Institutional food waste includes food waste generated at educational entities, hospitals, nursing homes, correctional facilities, and hotels/motels.

Residential food waste is generated at residential entities and military bases.

Due to data limitations, we were unable to analyze food waste at production (on-farm) level. As a reference, a food loss study by the USDA indicates that in developed countries, 2%–23% of total food supply is lost from production to retail sites, but no information is provided about food loss at farm locations (Buzby and Hyman, 2012).

2.4. Fats, oils, and greases

Fats, oils and greases (FOG) are generated during food preparation at food service establishments and at rendering plants where animal wastes from slaughterhouses and farms are processed into valuable products. The following three categories of FOG are included in this study:

Yellow grease is derived from used cooking oil generated at commercial and industrial cooking operations. It may also contain rendered animal fats.

Brown grease is waste grease recovered from traps installed in the sewage lines of restaurants/food processing plants and wastewater treatment plants.

Animal fats are a lipid material derived from slaughtered animals during rendering (a process that converts waste animal tissue into value-added products). This analysis includes the following animal fat categories:

- Inedible tallow (beef fat unsuitable for human consumption)
- Choice white grease (derived primarily from pork tissue, unsuitable