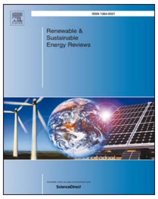
Renewable and Sustainable Energy Reviews xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser



Waste-to-Energy biofuel production potential for selected feedstocks in the conterminous United States

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ARTICLE INFO

Keywords:
Waste-to-Energy
WtE
Beneficial use
Waste resources
Hydrothermal liquefaction
HTL
Wastewater sludge
Manure
Food waste
Fats, oils, and grease
FOG
Biocrude
Jet fuel
Aviation kerosene
Bioenergy

ABSTRACT

Waste-to-Energy (WtE) technologies offer the promise of diverting organic wastes, including wastewater sludge, livestock waste, and food waste, for beneficial energy use while reducing the quantities of waste that are disposed or released to the environment. To ensure economic and environmental viability of WtE feedstocks, it is critical to gain an understanding of the spatial and temporal variability of waste production. Detailed information about waste characteristics, capture/diversion, transport requirements, available conversion technologies, and overall energy conversion efficiency is also required. Building on the development of a comprehensive WtE feedstock database that includes municipal wastewater sludge; animal manure; food processing waste; and fats, oils, and grease for the conterminous United States, we conducted a detailed analysis of the wastes' potential for biofuel production on a site-specific basis. Our analysis indicates that with conversion by hydrothermal liquefaction, these wastes have the potential to produce up to 22.3 GL/y (5.9 Bgal/y) of a biocrude oil intermediate that can be upgraded and refined into a variety of liquid fuels, in particular renewable diesel and aviation kerosene. Conversion to aviation kerosene can potentially meet 23.9% of current U.S. demand.

1. Introduction

Waste-to-Energy (WtE) technologies offer the promise of providing a synergistic relationship between industry and various levels of government to divert organic wastes such as wastewater sludge, agricultural and livestock waste, food waste, and municipal solid waste for beneficial energy use, while reducing the quantity of waste disposed and/or released to the environment. The approach is to make beneficial use of waste resources in a manner that 1) potentially eliminates, or at least significantly reduces adverse effects on public health, safety, welfare, and/or the environment; 2) contributes to sustainability factors; and 3) provides a net positive energy outcome. An important consideration in the WtE landscape is the waste management hierarchy (Fig. 1) that generally depicts a prioritization in the waste management process, wherein the focus is to minimize and divert waste, and then, only as a final option, dispose of it. This paper is centered on the beneficial use of waste resources after efforts have been made to reduce and avoid waste, and reuse, recycle, and compost waste where possible. The top of the hierarchy (waste reduction/avoidance) identifies the most preferred and sustainable option, and the least preferred and last resort option is waste disposal/release. The hierarchy is general, and a given feedstock and decision making around that feedstock may not always fit this structure. Some examples include 1) the conversion of waste to a biofuel may provide a higher value use than recycling/composting, and 2) reuse of wastewater sludge requires additional treatments to produce Class A/B biosolids, and thus a direct energy

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Abbreviations: BETO, U.S. Department of Energy's Bioenergy Technology Office; Bgal, billion gallons; CAFO, concentrated animal feeding operation; EERE, U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy; EPA, U.S. Environmental Protection Agency; FOG, fats, oils and grease; GL, gigaliters; HHV, higher heating value; HTL, hydrothermal liquefaction; IIC, industrial, institutional, and commercial; Mg, megagrams; Mgal, million gallons; MJ, megajoules; ML, megaliters; MT, million U.S. short tons; PNNL, Pacific Northwest National Laboratory; POTW, publicly owned treatment works; Tg, teragram; US, United States of America; VSS, volatile suspended solids; WtE, Waste-to-Energy

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http://dx.doi.org/10.1016/j.rser.2017.09.107
Received 28 April 2017; Received in revised form 6 July 2017; Accepted 26 September 2017

Please cite this article as: Skaggs, R.L., Renewable and Sustainable Energy Reviews (2017), http://dx.doi.org/10.1016/j.rser.2017.09.107

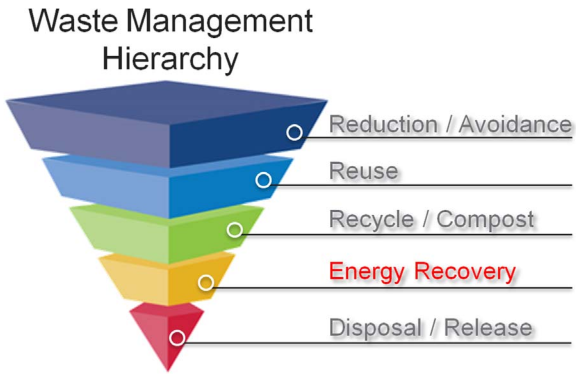

Fig. 1. Waste management hierarchy defining prioritization of handling waste, where reduction/avoidance is the most preferred and sustainable, whereas disposal/release is the least preferred and sustainable option.

recovery pathway may be more efficient.

These organic wastes provide a reservoir of carbon resources for energy production that otherwise represent mounting challenges associated with greenhouse gas emissions, pollutant reduction, and various measures of sustainability. In addition, trends toward more concentrated operations realize economies of scale—for example, fewer but larger solid waste landfills and fewer but larger concentrated animal feeding operations (CAFOs). Thus, a synergistic relationship among waste handlers offers an economic opportunity for converting waste liabilities into revenue streams or cost-neutral endeavors. Emerging trends toward decentralized fuel production also offer the opportunity to colocate properly scaled feedstock conversion facilities with a blend of compatible feedstocks. A critical challenge to ensuring the economic and environmental viability of WtE feedstocks is gaining an understanding of the spatial and temporal variability of waste production, characteristics, capture/diversion and preprocessing methods, transport requirements, available conversion technologies, and the overall energy return on investment. This understanding can then lead to more accurate estimates of energy and co-product production potential. Associated demand for other resources such as water, land, critical infrastructure, and additional opportunities for co-product generation (e.g., fertilizers) can also be evaluated.

The objective of this paper is to provide a foundation for a robust WtE industry that can capitalize on underutilized organic wastes for biofuels production in the conterminous United States. To support this objective, a comprehensive spatially enabled WtE feedstock database was developed that includes municipal wastewater sludge, animal manure, food processing waste, and fats, oils, and grease (FOG) [1,2]. This database development enabled us to carry out a detailed site- and feedstock-specific resource assessment to assess the biofuel production potential. Given the variability of these feedstocks and potential implications for downstream biorefinery design and operation, robustness in the energy conversion pathway (characterized by diversity, adaptability, and efficiency) is imperative. For the purposes of this initial assessment, we assumed hydrothermal liquefaction (HTL) to be the target pathway, because, as a conversion technology for wet biomass, it is rapidly approaching market readiness [3–6]. Results from these analyses will enable the U.S. Department of Energy and its stakeholders to accurately evaluate the scale and viability of WtE potential contributions to the Bioenergy Technologies Office Multiyear Program Plan target dry-weights of 245 Tg/y by 2017 and 285 Tg/y by 2022 [7].

This paper is organized as follows. Section 2 summarizes a resource assessment of selected WtE feedstocks for the conterminous United States including production potential and general characteristics. Section 3 provides an overview of HTL as a representative conversion pathway for these feedstocks to produce a biocrude oil intermediate. In Section 4, a reduced-form HTL conversion model, used to estimate the biocrude oil production potential of each feedstock, is described. Results of the biocrude oil production assessment, including the spatial distribution of the feedstocks, are summarized and discussed in Section 5. Section 6 highlights the key conclusions and recommended next steps for this research.

2. Selected WtE resources overview

2.1. Wastewater sludge

Management and disposal of municipal wastewater sludge is a significant challenge throughout the United States and can be of considerable expense to treat and/or dispose given its significant volume, high water content, and pollutant concentrations (e.g., pathogens, heavy metals, pharmaceuticals, persistent organics, etc.). Generally, the methods and practices for wastewater treatment and sludge management in the United States are founded in engineering traditions dating to the early 20th century, and are primarily driven by considerations of function, safety, and cost-benefit analysis. However, looking to the future with a sustainability and beneficial-use perspective, wastewater can be viewed as a renewable resource from which we can recover water, nutrients, and energy produced from the high organic content in the waste stream. Maximizing water reclamation and unconstrained reuse can be an important asset in water-stressed areas.[1] As an example of energy recovery, anaerobic digestion has been practiced for decades to generate methane for onsite heat and/or electricity generation, and some facilities have achieved or neared a net-zero energy footprint. At many facilities, the production of biosolids for fertilizer/soil amendments is a beneficial use of the sludge waste; however, social concerns about this practice have increased with regard to heavy metals and pharmaceutical compounds being introduced to soils used for crop production [8]. As such, current wastewater treatment practices are believed to predominantly have a negative effect on local/regional water, energy, and material sustainability [9]. Additionally, there is an increasing frequency of cases throughout the United States where summertime algal blooms severely affect freshwater resources (municipal water, irrigation water, recreation, wildlife, etc.). In part, this results from long-term accumulated and excess available nitrogen and phosphorous within the aquatic environment in combination with warm water bodies (i.e., shallower water depths; higher summertime temperatures) that provide favorable growing conditions for varying types of algae and cyanobacteria [10–13]. In the future, areas more prone to algal blooms may require the diversion of treated wastewater streams or be subject to increased regulation of nutrient concentrations released in treated wastewater. Addressing such diversion or regulatory needs can in part be solved by the beneficial use of sludge, including HTL processing for biocrude oil and nutrient recovery [14].

Within a given publicly owned treatment works (POTWs) design, a number of unit processes can be implemented for sludge processing, depending on the plant design and operation, plant objectives, and characteristics of the waste stream being processed [15,16]. The principal sources of sludge considered for WtE in this study are primary and secondary treated waste. Primary treatment involves the initial clarification or settling of suspended solids (i.e., primary sedimentation). Chemical flocculants are often used to increase the efficiency (time to settle and total solids) of solids settling. Primary treatment consists of concentrating organic solids and inorganic fines to 2–7% concentration, where 40–70% of total suspended solids are captured with an approximate solids production of 0.1–0.3 kg/m^3 of wastewater [17,18]. Volatile suspended solids (VSS) concentration generally ranges from 60% to 85%.

Secondary treatment is focused on biological treatment and involves a combination of aeration, exposure to microbes, and secondary clarification through additional solids settling (i.e., secondary

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[1] One example is the Pure Water San Diego project: http://PureWaterSD.org.