U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

# Biofuels and Bioproducts from Wet and Gaseous Waste Streams: Challenges and Opportunities

## Bioenergy Technologies Office

January 2017

***Updated***

## Executive Summary

*An earlier version of this report was published January 10, 2017. This version includes corrections to the inherent energy content of food waste and to the estimated annual $CO_2$ resource availability.




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# Executive Summary

Historically, the concept of "waste-to-energy" has referred to any of a number of highly mature technologies (e.g. incineration or anaerobic digestion) that decrease waste volumes. Landfill capacity scarcity, coupled with increasingly stringent disposal regulations, is necessitating novel waste management solutions. In particular, the notion that waste streams represent valuable feedstocks for the production of biofuels and bioproducts is gaining currency. These feedstocks include inedible fats and greases, biogas from landfills, dairies, wastewater treatment plants, and the organic fraction of municipal solid wastes. Conversion of these feedstocks into renewable natural gas, diesel, and aviation fuels is just beginning to gain market traction. It represents a significant opportunity for additional expansion.

Terrestrial feedstocks are currently the largest resource generated for the bioeconomy, estimated at 572 million dry tons for 2017 (Billion Ton 2016), and have traditionally constituted the primary focus of the Bioenergy Technologies Office (BETO). However, the resource assessment conducted by the National Renewable Energy Lab and Pacific Northwest National Lab indicates that wet waste feedstocks (Summarized in Table ES-1) could also make significant contributions to the bioeconomy and domestic energy security goals.

**Table ES-1. Summary of Annual Wet and Gaseous Resource Availability**

| | Annual Resource Generation | | |
|---|---|---|---|
| Feedstocks | Estimated Annual Resources | Inherent Energy Content (Trillion Btu) | Fuel Equivalent (MM GGE)[1] |
| Wet Feedstocks | 77.17 MM Dry Tons | 1,078.6 | 9,290.8 |
| Wastewater Residuals | 14.82 | 237.6 | 2,046.6 |
| Animal Waste | 41.00 | 547.1 | 4,713.0 |
| Food Waste[2] | 15.30 | 79.6 | 685.3 |
| Fats, Oils, and Greases | 6.05 | 214.3 | 1,845.9 |
| Gaseous Feedstocks | | 733.6 | 6,319.8 |
| Biogas[3] | 420 BCF | 430.5 | 3,708.6 |
| $CO_2$ Streams | 3,142 MM Tons | - | - |
| Associated Natural Gas | 289 BCF | 303.1 | 2,611.2 |
| Other Waste Feedstocks | | 526.1 | 4,531.6 |
| Glycerol | 0.6 MM Tons | 8.7 | 75.1 |
| Black Liquor | 44 MM Tons | 517.4 | 4,456.5 |
| DDGS[4] | 44 MM Tons | n/a | n/a |
| Total | | 2,338.3 | 20,142.2 |

[1] 116,090 Btu/gal. This does not account for conversion efficiency.
[2] The moisture content of food waste varies seasonally, ranging from 76% in the summer to 72% in the winter.
[3] Methane potential. This does not include currently operational landfill digesters (>1,000 billion cubic feet [Bcf] annually) and may double count potential from wastewater residuals, food waste, and animal waste.
[4] DDGS = Dried Distillers Grains with Solubles
Note: The inherent energy content of food waste and estimated annual $CO_2$ resources have been corrected from a previous version of this report published January 10, 2017.

When combining the primary waste streams of interest: sludge/biosolids, animal manure, food waste, and fats, oils, and greases, a supplemental 77 million dry tons per year are generated. Of this total, 27 million dry tons is currently being beneficially used (e.g. fertilizer, biodiesel, compost), leaving 50 million dry tons available for conversion to biofuels, bioproducts or biopower. Gaseous waste streams (biogas and associated natural gas) contribute an additional 734 trillion Btu (TBtu), bringing the total energy potential of these feedstocks to over 2.3 quadrillion Btu. Additionally, these streams contain methane, the second most prevalent greenhouse gas, which constituted 12% of net U.S. emissions in 2014 according to the U.S. Environmental Protection Agency's (EPA) greenhouse gas inventory.[1] Thus, there is significant potential to valorize these energy dense streams while simultaneously reducing harmful emissions.

As illustrated by example in Figure ES-1, wet and gaseous waste streams are widely geographically distributed, frequently in areas of high population density, affording them unique current and emerging market opportunities. The size of publicly owned treatment works, landfills, rendering operations, and grease collectors overlay with the largest population centers nationwide. Therefore, when compared to terrestrial feedstocks, these waste streams are largely aggregated and any derivative biofuels, bioproducts, or biopower are close to end markets.

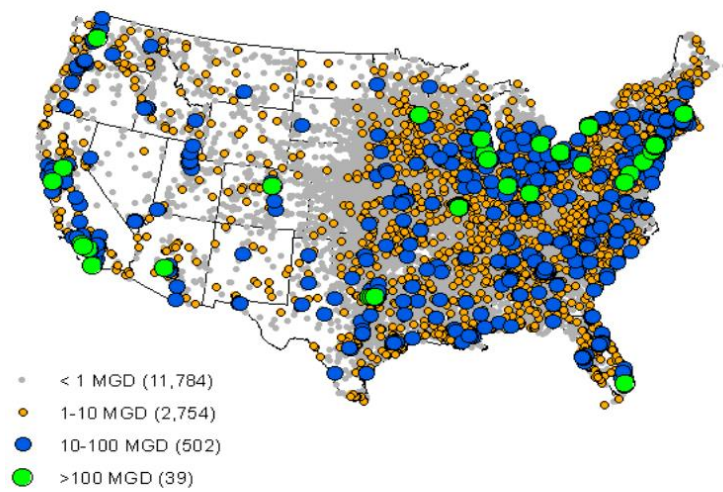


**Figure ES-1. Spatial distribution and influent range of 14,581 US EPA 2012 Clean Water Needs Survey (CWNS) catalogued treatment plants**

At the same time, however, this close proximity to populations markets often correlates with more stringent regulatory landscapes for disposal. Therefore, the value proposition presented by these waste streams commonly includes avoiding disposal costs as opposed to an independent biorefinery that requires stand-alone profitability. Aided by these and related factors, public and private entities are actively exploring and deploying novel solutions for waste stream valorization. Potential competition between biofuels, bioproducts, and other beneficial uses will likely be a key element of future markets, and clearly merits further analytical and modeling investigation.

While there are advantageous market and policy factors unique to these feedstocks, they are subject to significant compositional, geographic, and temporal variability. This variability creates unique challenges and requires conversion technologies that are tailored towards particular families of feedstocks. Wet and gaseous feedstocks also represent a unique set of challenges in terms of feedstock acquisition and handling. This report explores conversion possibilities for both wet and gaseous feedstocks at a wide variety of technology readiness levels. With some exceptions, the early stage nature of many of these technologies suggests an "all-of-the-above" strategy at relatively low initial funding levels can provide an environment that encourages natural selection of solutions as they move closer to market. The U.S.

[1] EPA greenhouse gas inventory: epa.gov/sites/production/files/2016-04/documents/us-ghg-inventory-2016-main-text.pdf

Department of Energy's Small Business Innovation Research program might be an excellent vehicle to pursue such a strategy.

As a counter example, hydrothermal processing techniques using near-critical water have benefited from prior funding under BETO's algae and conversion research and development platforms and are nearing the point where pilot testing is appropriate. Work to date indicates that these and related technologies could process diverse blends of these wet waste feedstocks offering potential for widespread deployment. The subcritical hydrothermal efforts so far represent only a small part of the possibilities in this area; supercritical water also offers intriguing options, as do other fluids at high temperature and pressure, such as $CO_2$.

There are several other conversion technologies under investigation for both wet and gaseous waste feedstocks. Variations on anaerobic digestion, including arrested methanogenesis, anaerobic membrane reactors, and various pre and post- treatment strategies all appear to have potential. Microbial electrosynthesis may also have promise, and novel monitoring strategies could serve as enabling technologies for future developments. In terms of gaseous resources, thermochemical, biochemical, and electrochemical strategies all have some merit, as do various combinations of the three. What seems clear is that exploration of a broad range of possibilities, followed by a rigorous down selection process has a good chance of producing market-relevant results.

It is also clear that feedstocks, markets, and technologies as articulated in chapters two through four need to be treated as holistic units. The wet and gaseous streams highlighted in this report will only penetrate the markets of the future if they make economic sense. Additionally, sustainability considerations that include the triple bottom line of economic, environmental, and social factors will be critical in helping to construct the bioeconomy of the future. Bioproducts will also be a key economic incentive for biofuels, and regulatory drivers are likely to play an increasing role in the disposal of organic wastes in landfills and other actions at the state and local levels.

This report concludes that wet and gaseous organic waste streams represent a significant and underutilized set of feedstocks for biofuels and bioproducts. They are available now, in many cases represent a disposal problem that constitutes an avoided cost opportunity, and are unlikely to diminish in volume in the near future. As a result, at least in the short and medium term, they may represent a low-cost set of feedstocks that could help jump start the Bioeconomy of the Future via niche markets. While much modeling, analysis, and technological de-risking remains to be done in order to bring these feedstocks to market at significant scales, the possible contributions to the overall mission of the Bioenergy Technologies Office merit further attention.

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DOE/EE-1472 • January 2017