Emerging Manure to Energy Technologies

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Bioenergy Options

Figure 4.13 Main bioenergy conversion routes

ANAEROBIC DIGESTION

Manure, Crops, Wastewater Sludge Food Waste ANY ORGANICS

Biogas

CH₄ (Methane)

Anaerobic Environment

(1) Hydrolysis ➔ fatty acids, sugars
(2) Acidogenesis ➔ alcohols CO₂, H₂
(3) Acetogenesis ➔ acetic acid, CO₂, H₂
(4) Methanogenesis ➔ CH₄ and CO₂

Liquid Fertilizer with 25 - 80% Less Solids and ≈ 50% More Dissolved Nutrients
Conversion of biomass to biogas and to usable energy

Usable substrates:

- Energy crops
- Manure
- Residues or byproducts of food-production (e.g., kitchen-waste)

Biogas Process

- H₂S scrubbing
- CO₂ Scrubbing Compression
- Gasboiler (heat)
- CHP-Unit (electricity, heat)
- Pressure-storing
- Green gas, SNG
Anaerobic Digesters in the World

The majority of US digesters are at WWTP, only 260 on-farm
DC Water processes 370 million gallons of wastewater per day and uses thermal hydrolysis to “pressure-cook” the waste solids prior to AD. This is the largest thermal hydrolysis plant in the world.

The digesters are expected to produce 13 MW of electricity (enough to power 8,000 homes and a $10 million savings annually). With additional generation possible with incorporation of off-site food waste, fats and grease.

They will save $10 million in trucking costs and reduce their carbon emissions associated with transportation by half.
Lack of US Small-scale on-farm Digestion in the US

Of the 260 farm-based US digestion systems only FOUR dairy digesters are on farms with 200 cows or less (87% of dairy farms).

<table>
<thead>
<tr>
<th>Number of Dairy Cows on-Farm</th>
<th>Number of US Operations (2012)</th>
<th>Percent of Total US Dairies</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-29</td>
<td>18,800</td>
<td>32%</td>
</tr>
<tr>
<td>30-49</td>
<td>9,700</td>
<td>17%</td>
</tr>
<tr>
<td>50-99</td>
<td>14,500</td>
<td>25%</td>
</tr>
<tr>
<td>100-199</td>
<td>7,900</td>
<td>14%</td>
</tr>
<tr>
<td>200-499</td>
<td>3,800</td>
<td>7%</td>
</tr>
<tr>
<td>500+</td>
<td>3,300</td>
<td>6%</td>
</tr>
</tbody>
</table>

Adapted from: USDA, NASS Farms, Land in Farms and Livestock Operations
Small-Scale Digesters for US

Six flexible biogas bags digesters situated in insulated, heated culverts
Influent can be pre-heated and radiant piping used for in-vessel heating
Automatic loading and temperature control at 30°C
Food Waste Co-digestion at Kilby Farm

Covered lagoon dairy manure digester – currently unheated – in Colora, MD

• Food processing waste from manufacturing of Cranberry, Ice cream, Chicken and Meatballs and manure from 600 cows.

• Digester input consists of 96.8% (by volume) dairy manure and the remaining is the food waste.

Lisboa and Lansing, 2013 in Waste Management
Anaerobic Digestion of Poultry Manure

Very few digesters in the US – most European digesters only co-digest poultry litter.

For litter-only digesters, you need to add water.

AD product is liquid, solids can be separated and the liquid can be field applied or re-used if ammonia is removed due to ammonia inhibition during AD.

Digestion largely conserves N and P (5-20% reductions), but allows for further nutrient management. Struvite formation and/or ammonia scrubbing of effluent, resulting in a solid nutrient product that can be more easily transferred off-farm and removed from the poultry litter matrix.
Watershed Implications of Digestion: Nutrient Management

- Regulatory oversight of AD is based on how digestion fits into a farm’s nutrient management plan.
- The digester effluent has most of the nutrients from the manure conserved,
  - Nutrients in a dissolved form for land application.
- Food waste that is co-digested will also have nutrients that will be applied.
- Most U.S. operations separate manure solids post-digestion and then compost or reuse as bedding, which decreases on-farm expenses and reduces phosphorus soil additions due to recycling within the bedding material.
Digestion Challenges ($ $ $ $ $)

- Understanding dairy industry pressures and low economic return from manure-only waste digestion and infancy of poultry litter based digesters (3 in US)

- Importance of scrubbing H2S from biogas, especially for electric generation and frequency of generator malfunction

- Dependent on electricity price for large-scale systems and year-round demand for direct use of biogas for small-scale systems for economic return
  - Most treatment systems do not have an economic return

- Difficulties and time to obtain financing and operate

Klavon, Lansing et al., 2013 in Biomass & Bionenergy
Digestion Opportunities

- Livestock operations have consistent biomass collected in one spot that without digestion is a source of GHG emissions, but with digestion can produce energy non-intermittent renewable energy with a small land footprint.

- Reduce farmer-incurred capital costs and realize that small-scale farms are >50% of the market. (Operate at seasonally lower temperatures with alternative inoculum sources)

- In Germany, with 8,000 digesters, the overwhelming majority incorporating co-digestion. Co-digestion of food waste, with tipping fees (more $$ to farmers) can greatly increase energy production, assuming the nutrients from the food waste can be incorporated into nutrient management plans.

- The USEPA has identified more than 11,000 viable agricultural AD systems using current technology, which could power 3 million homes and could reduce methane emissions by 54 million metric tons of CO$_2$ (eq), equal to emissions from 11 million passenger vehicles.
Incineration
- Combustion
- <400 degrees C
- Requires specific oxygen ratio
- Produces Heat and toxins

Pyrolysis
- Chemical Reaction
- 400 – 850 degree C
- Produces combustible gas, char

Gasification
- 850 – 1400 degree F
- Controlled amounts of oxygen

Gasification
- 850 – 1400 degree F
- Controlled amounts of oxygen

Plasma Gasification
- >1400 degrees C
- Oxygen starved

Toxins Produced / Oxygen Supply / Simplicity

Temperature / Energy Produced / Energy required / Range of inputs / Costs / Complexity
Biomass Gasifier

Gasifies at \( \sim 1850 \, ^\circ F \) to syngas, mixture of CO and H\(_2\) and CH\(_4\) that is burned in turbines to generate electricity

McNeil Gasifier: 200 tons of wood chips daily from forest thinnings and wood pallets

BioChar is the by-product created, which is bio-based charcoal in the form of graphite carbon that can be used in soils, with high internal surface area, adsorption properties, and cation exchange capacity (CEC), resulting in better fertilizer retention and less field runoff.

http://www.nrel.gov/biomass/photos.html
Poultry Litter Gasification System

- Gasifier loading
- Expansion chamber
- Temperature control
- Flare line
- 20 kW generator

University of Maryland
### Emissions of Bio-based Electricity

#### Table 4.5 Net life cycle emissions from electricity generation in the UK

<table>
<thead>
<tr>
<th>Source</th>
<th>CO₂</th>
<th>SO₂</th>
<th>NOₓ</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Combustion, steam turbine</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>poultry litter</td>
<td>10</td>
<td>2.42</td>
<td>3.90</td>
</tr>
<tr>
<td>straw</td>
<td>13</td>
<td>0.88</td>
<td>1.55</td>
</tr>
<tr>
<td>forestry residues</td>
<td>29</td>
<td>0.11</td>
<td>1.95</td>
</tr>
<tr>
<td>MSW (EfW)</td>
<td>364</td>
<td>2.54</td>
<td>3.30</td>
</tr>
<tr>
<td><strong>Anaerobic digestion, gas engine</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sewage gas</td>
<td>4</td>
<td>1.13</td>
<td>2.01</td>
</tr>
<tr>
<td>animal slurry</td>
<td>31</td>
<td>1.12</td>
<td>2.38</td>
</tr>
<tr>
<td>landfill gas</td>
<td>49</td>
<td>0.34</td>
<td>2.60</td>
</tr>
<tr>
<td><strong>Gasification, BIGCC (2)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>energy crops</td>
<td>14</td>
<td>0.06</td>
<td>0.43</td>
</tr>
<tr>
<td>forestry residues</td>
<td>24</td>
<td>0.06</td>
<td>0.57</td>
</tr>
<tr>
<td><strong>Fossil fuels</strong></td>
<td></td>
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<tr>
<td>natural gas: CCGT (2)</td>
<td>446</td>
<td>0.0</td>
<td>0.5</td>
</tr>
<tr>
<td>coal: ‘best practice’</td>
<td>955</td>
<td>11.8</td>
<td>4.3</td>
</tr>
<tr>
<td>coal: FGD &amp; low NOₓ (3)</td>
<td>987</td>
<td>1.5</td>
<td>2.9</td>
</tr>
</tbody>
</table>

1. Note that 1 g kWh⁻¹ is the same as 1 t GWh⁻¹.
2. See Box 4.8
3. Flue gas desulphurization and low NOₓ burners.

Source: Adapted from ETSU, 1999
UMD Waste to Energy Projects

- Post-digestion nutrient capture from liquid digestate of poultry litter digesters
- Gasification of poultry litter
  - Life cycle assessment (LCA) comparing the two poultry litter waste-to-energy technologies
- Effect of digestion and composting on antibiotic transformations with modeling of field to stream outputs
- Cover crop (radish) co-digestion with manure to increase biogas yield and cover crop utilization
- Digesters for University of Maryland campus food waste
- Digesters for low-cost sanitation options in Haiti
- Digester effluent into Microbial Fuel Cells for further nutrient treatment and direct electricity production
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